NUCLEAR ENGINEERING VOL. 3 NO. 28 JULY, 1958

Enrichment:—A National Policy

AN all out effort on the AGR appears as the main message of Sir Christopher Hinton, Chairman of the C.E.G.B. to the British electrical industry which held its annual Power Convention in Brighton during the week June 16-20, coupled with a warning that unless its development were successful and capital costs of nuclear stations were materially reduced the trend away from fossil fuelled power stations might be reversed. Although the C.E.G.B. is not committed to an irrevocable policy of installing only strictly competitive plant, Sir Christopher indicated that once the base load requirement had been filled—which would be by stations beginning construction in 1966-67—then contracts for nuclear plant might reduce to 300 MW to 400 MW per annum, accommodating only the base load increase. In any case, coal-fired power stations are now to be built after 1966-67 and at a rate in excess of 50% of that obtaining today, in spite of forecasts that an all nuclear programme would be initiated in eight to ten years' time.

It is interesting that starting from quite opposite positions, both the U.K. and the U.S.A. are now at the same time to give high priority to an enriched uranium gas-cooled, graphite-moderated reactor. Strictly speaking, studies are not complete in the U.S.A. and Congress has not yet approved construction, but there is little doubt that funds will be granted and building will begin at the N.R.T.S. at the end of the year. Parallel development—one hopes with co-operation—in the two countries should make for a most interesting situation, as no doubt final designs will differ significantly due to different backgrounds and philosophies.

An initial divergence is demonstrated in the ORNL GCR-2 analysed in this issue (p.277 et seq.) which uses helium as coolant. This is recognized as having disadvantages because of limited availability—although this aspect is perhaps over emphasized—and the KE/ACF study with CO_2 as coolant is more likely to form the basis for the U.S. building project. One advantage that the U.K. will have in development is a larger background of experience in the gas-cooled field, particularly in regard to the C/CO_2 reaction, which may prove to be the limiting feature of the system, although the U.S. has a greater knowledge of UO_2 behaviour and fabrication techniques.

The U.S.A. in its studies has determined on the use of stainless steel as a cladding material, preferring the added enrichment to the increased cost and difficulties of beryllium canning. There have been suggestions recently in America that the cost of beryllium, however, might be reduced from the quoted figure of $47/lb as-cast ingot to $20/lb. Whether beryllium is finally adopted in the U.K. is still a matter for speculation. Before it can be used on anything like a mass production scale, the problem of two dimensional ductility must be solved and this is no easy matter. Past experience indicates that, provided sufficient effort is expended, any mechanical problem can be solved (whilst other problems are neglected), and as we have already invested a great deal in the development of this metal it is possible that we are already past the point of no return. This is not to say that stainless steel has been ignored in the United Kingdom, but concerned with limiting enrichment, a cladding thickness of 0.007 in. is being considered as against 0.020 in. in the ORNL design. With such a thin can, the margin for error is small.

But, beryllium or stainless steel, thick or thin, enrichment is necessary. Is the U^{235} to be produced in the U.K. and, if so, is the power programme to be geared to material made in the Capenhurst diffusion plant where size and power cost considerations would indicate enriched uranium to cost something over three times the U.S. figure (whilst unconfirmed reports quote a figure much in excess of this)? A low cost supply of enriched material ceases now to be a matter of academic wishfulness—but represents a challenge of considerable importance. At present there is no agreement with the U.S.A. for the purchase of enriched uranium for industrial power purposes, although there is little doubt that this could be negotiated. It is possible that such an agreement may not be necessary in view of the projected modifications to the McMahon Act, but if national policy and pride prevent our purchasing from the U.S.A. would it not be wise, and appropriate, to construct a diffusion plant within the Commonwealth at a place where power costs are low and a surplus exists, for example at Kitimat in British Columbia where aluminium production is falling off. Alternatively, of course, we could associate with Euratom in a vast European plant.

Industry (and the A.E.A.) is being asked to make a great effort on the development of the AGR and, in effect, a time limit has been set. If (in the words of Sir Claude Gibb) it were possible to have firm prices quoted for enriched fuels and their availability to be assured without any form of reservation, then the reactor designer's problems would be greatly simplified.

Fuel Element Trends

HIGH fabrication costs for plate-type elements are resulting in a progressive movement towards tubular construction. In the liquid-cooled reactor field also more attention is being paid to the use of aluminium because of cheapness and because new alloys offer good corrosion resistance to high-temperature water whilst still retaining excellent fabricational qualities. ALPR—the boiling water counterpart of APPR—being built at Idaho Falls and due for commissioning this year will incorporate fuel canned in an aluminium nickel alloy x8001 developed by Argonne and first used in BORAX 4. It is estimated that substitution for the Zircaloy-clad U-Zr-Ni alloy plates as used in EBWR by Al-alloy canned UO_2 pellets would bring fabrication costs down by a factor of ten (from $700 to $70). Recent experiments indicate that heat ratings similar to those that have been demonstrated with the existing core can be achieved.

In view of the remarkably low activity recorded in the EBWR turbine when it was stripped down recently, in spite of a simulated faulty element having been in the core for the week previously, activation should present a negligible hazard. On the other hand a progressive plating out of cobalt is being observed on the heat exchanger tubes and in the pressurizer of APPR. This is not dramatic, but sufficiently serious to warrant investigation into inhibitors and the substitution of say Inconel for the heat exchanger tubes; the activity is believed to originate in the stainless steel plate cladding. An intrinsically cobalt-free material would clearly have advantages. Nevertheless, the core of APPR-1A will be substantially identical to APPR.

In Canada where the revised outline design of NPD-2 is complete (this is a 200 MW(E) heavy water calandria-type reactor with horizontal pressure tubes) it is anticipated that Zircaloy-II will be used as constructional material for the pressure tubes, but the possibility of substituting an aluminium alloy is not ruled out.

Fuel elements for the organic moderated reactor to be installed at Piqua, Ohio, are not yet finalized, but aluminium-clad uranium metal is being seriously considered. Should this prove to be feasible, element fabrication costs should be near the minimum, although the top temperature restrictions that aluminium impose would appear to vitiate exploitation of the full potentialities of the organic system.

Strauss Retires From U.S.A.E.C.

THE retirement of Mr. Lewis Strauss from chairmanship of the A.E.C. should at least ease the growing tension between the Commission and Congress. Strauss has provided a political target for the Democrats now for many months and it is perhaps surprising that the A.E.C. programme has not suffered more than it has. Focal point of criticism concerns the power development programme in the U.S.A. Whilst Congress, against decreasing opposition, has pressed for an energetic power building programme financed by the federal government, Strauss has strongly opposed the move on the grounds that this was a matter for private industry. In a recent discussion with *Nuclear Engineering*, he emphasized his conviction that the proper way for America to tackle the power reactor programme was to leave construction to private industry and for the A.E.C. to provide basic information only and to encourage industrial investment through the medium of its power demonstration programme. The building of uneconomic power stations with federal funds is interpreted by Strauss as a direct entry into the utility field at complete variance with American standard policy and the American way of life. Acknowledging that there are hard times in the immediate future, Strauss believes that direct industrial competition will result in some companies at present nominally engaged in reactor design and construction leaving the field, but believes that this will be to the ultimate good of the industry and that, whilst the weakest go to the wall, the stronger will gain in experience and will ultimately be better equipped and capable of cheaper and better production.

Industry in the main, whilst agreeing with the basic principles of this philosophy, is seriously concerned about the immediate years that lie ahead. Apart from the few power stations which the utility companies have commissioned, largely for prestige reasons, there is unlikely to be a home market except in small, high cost areas such as New England and Florida for something like 10 years. Although A.E.C. development contracts enable industry to maintain large establishments and design teams, by British standards, on individual projects are small, it is felt that this is an unsatisfactory long-term situation, and competition for the contracts is too keen, many being placed as a result of bids which are unrealistically low. At the same time the cost plus system, on which most of these contracts are based, usually allows a sufficient margin for the contracting company to break even—the Elk River contract which is on a fixed price downwards basis being unusual.

The proposal for a federal sponsored building programme has been raised in Congress twice; at the second time was defeated by only a narrow majority. This question is certain to be raised again and there is a strong likelihood that on the third attempt the Bill will be passed and the A.E.C. will be forced to accept this decision.

In its relations to Britain and the rest of the world, Strauss indicated that there was unlikely to be any noticeable change. There was a reasonable unanimity of opinion within the Commission on the proper approach to Britain and Euratom and the present policy was unlikely to be modified. How far the U.S. is prepared to go in co-operating with Europe, notably through Euratom, was not made clear but it would appear unlikely that any direct subsidy for the building of U.S. power stations in Europe would be provided.

DIGEST...

A Brief Survey of Significant News

U.K. Seeks Purchase of Nuclear Sub. Propulsion Unit

". . . approach the Government had recently made to the U.S. for approval to purchase one nuclear submarine propulsion machinery unit from an American firm"—announcement by First Lord of the Admiralty. Approval is conditional upon revision of McMahon Act, and agreement upon release of information concerning fuel elements in Calder-type reactors. Previous difficulties reported resolved in recent meeting between MacMillan and Eisenhower. "Dreadnought" project as a result will be much modified but development work is not to be discontinued.

Dungeness Proposed As Site for the Next C.E.G.B. Nuclear Station

Sixth British nuclear power station will be built west of Dungeness lighthouse, if the Ministry of Power and the local planning authority agree to the recent C.E.G.B. proposal. The site certainly seems excellent. It is large; no agricultural land is involved; there is plenty of water close in shore and trial bores have shown that the foundations will support heavy reactors. Incidentally, the C.E.G.B. has already decided to extend the 275-kV transmission line to nearby Lydd to interconnect with the French electricity system via the proposed cross-Channel cable. If the site is approved, we understand that tenders will be requested by the end of this year and that a contract will be awarded next spring.

17 MW Heavy Water Power Reactor Approved by A.E.C.

Carolinas Virginia Nuclear Power Associates are proposing to build a 17 MW(E) heavy-water cooled and moderated pressure tube reactor fuelled with slightly enriched uranium. The U.S.A.E.C. has agreed to support the proposition on a cost-sharing basis. The Associates will pay the capital costs of $22 million and the A.E.C. will contribute a further $14,655,000 to the cost of research and development. Fuel charges will be waived for the first five years. Anticipated date of criticality is June 30, 1962.

U.K. - Euratom Co-operation; Preliminary Moves

Technical agreement for collaboration between the institutions and industries of Euratom countries and the U.K. is being actively pursued by the Government, Mr. R. A. Butler announced in the Commons on May 22. As a first step, Sir William Meiklereid has been appointed U.K. representative to Euratom.

At the B.E.P.C., Sir George Nelson called for a close touch to be kept with developments on the Continent and urged the Government to implement its suggestions for providing long-term finance for overseas projects.

No Future for 10 MW Aqueous Homogeneous Reactor?

There is little or no early economic promise for a small aqueous homogeneous power reactor similar to the demonstration reactor proposed by Wolverine Electric Co-operative, according to the U.S.A.E.C. The project has now been dropped. Under the Commission's power demonstration reactor programme Wolverine proposed to build a 10 MW(E) station. The A.E.C. accepted the proposal and Congress appropriated funds but Foster-Wheeler, the main contractor, subsequently withdrew because of a three-fold rise in estimated cost.

HAR Project Abandoned

The HAR project as such in U.K. has now ceased to exist and discussions on the system were omitted from the Technology Conference for industry held at Harwell on June 11. Experimental programme on HAZEL—the zero energy homogeneous system has been curtailed but not stopped entirely.

Mid-West Universities Form Co-operative

Twenty-six leading U.S. educational and research institutions have formed a non-profit making inter-university corporation called Associated Midwest Universities. Headquarters for AMU will be located at Argonne National Laboratory—the nation's senior research and development centre for peacetime uses of atomic energy. Although AMU will make use of facilities at Argonne, it will not be confined to nuclear science.

Fuel Element Fire in NRU

NRU in Canada is likely to remain shut down for 3-4 weeks following a uranium fuel rod fire on the night of May 24. The reactor was shut down at the time of the accident to remove a defective rod; this operation proved difficult and part of the rod broke off and caught fire. The fire was quickly extinguished but some radioactive dust was spread through the building. No one was injured and the reactor and rod removal equipment were not damaged.

RWE Reactor Projects Develop

Tenders for a 200 MW station for RWE in West Germany are expected from the British Consortia shortly. In parallel with this full-scale gas-cooled station, RWE are to investigate the BWR and are concluding negotiations for a 15 MW unit similar to the Vallecitos reactor with A.E.G. in conjunction with General Electric. Negotiations between RWE and AMF Atomics for a 15 MW reactor broke down following the A.E.C.'s refusal to sanction core design.

Power Reactor Project Initiated in Spain

Internuclear Company has been retained by Centrales Nucleares del Norte, S.A., NUCLENOR, to conduct preliminary studies on plans to build a nuclear power plant of 220-250 MW(E) in Northern Spain. Consideration of factors pertinent to the selection of a site are already under way. Sir David Eccles, President of the B.o.T., returning recently from a visit to that country expressed the view that Spain would buy reactors in the U.K.

Keel of N.S. Savannah Laid

Keel of the first U.S. nuclear ship, *N.S. Savannah*, was laid at Camden, New Jersey, on May 22. The *Savannah* due to make her maiden voyage in 1960 will be a floating laboratory-cum-good-will ambassador for the U.S. She will house 60 passengers and carry 9,400 tons of cargo. Estimated cost—$31 million.

No Fouling Indicated in OMRE

OMRE has now completed three months' operation at full design power of 6 MW. So far it has not been possible to visually examine fuel elements but heat transfer measurements indicate no tar deposition. Energy absorption in organic, owing to use of PWR core, is about three times that expected in power reactors. Make up is 500 lb/d against 1½ lb/MWh(t) possible in reactor with designed core. Commercial grade of isomers of bi- and tetra-phenyl used in reactor at present priced at $0.17/lb.

Strauss Leaves, McCone Made Fifth Board Member of U.S.A.E.C.

Mr. Lewis Strauss will not be reappointed as chairman of U.S.A.E.C. when his term of office expires this month. Instead, he will act as consultant to President Eisenhower with special (not exclusive) duties towards the International Agency. Mr. John McCone, chairman of Pacific Far East Lines, nominated as fifth member of board. New chairman not to be announced before McCone confirmation by Congress. Possible successor to Strauss: Dr. Willard E. Libby is the only scientific member of the board.

$200 Million Civilian Building Budget Proposed by U.S.A.E.C. for 1959

Request for authorization of U.S.A.E.C.'s 1959 construction programme is being studied by the Joint Congressional Committee on Atomic Energy. Programme calls for expenditure of $193,379,000—including $51 million for a 40 MW prototype gas-cooled graphite-moderated power reactor; $8 million for a heavy water test reactor and $3 million for a prototype 10-MW preassembled package power plant for rapid erection at military bases. A.E.C. has also asked for an additional $26¾ million for this year's power reactor demonstration programme.

Reactor News in Brief

SRE in California reached design power level of 20 MW on May 21. . . .
DMTR (Dounreay materials testing reactor) went critical May 24. . . .
PWR at Shippingport dedicated by President Eisenhower on May 26. . . .
ORR at Oak Ridge brought to design power of 20 MW on May 29. . . .

Prospective Entrants for the "Nuclear Engineering" Post-Graduate Scholarship are reminded that entries must be received by July 30.

GCR2—The ORNL Design Study

This article details the main features of the enriched uranium gas-cooled graphite moderated reactor designed by Oak Ridge National Laboratory.

ENRICHED fuel, helium cooling, stainless steel canning and a burn-up of more than 7,000 MWD/t are some of the distinctive features of the GCR2 gas-cooled reactor design study carried out by the staff of the Oak Ridge National Laboratory* and recently released. It is one of two separate studies which were instigated by the A.E.C. in late September, 1957, the other being undertaken by Kaiser Engineers; both being based on mutually agreed "ground rules" so that direct comparisons could be made.

The reasons for the unorthodox (by British and French standards) materials are summarized; the physics of the system are analysed in the article beginning on p. 282.

Fuel

One of the major items in the design is the use of enriched fuel, which permits the use of uranium oxide instead of metallic uranium; thus eliminating the mechanical deformation which is one of the metal's chief handicaps. Enriched fuel also enables stainless steel canning to be used.

From the economic standpoint, particularly in the U.S., enrichment does not necessarily indicate a substantial fuel cost penalty, since it at once permits operation at higher specific power levels. Also, by enriching beyond the level required for mere criticality, the poisoning effect of Pu^{240} can be overcome to the point where it begins to behave as a fertile material through the production of fissionable Pu^{241}, and to give an increased burn-up significant enough to make the overall fuel costs comparable with those of a natural uranium reactor.

A further effect of enrichment is to bring about a shift in the absorption competition between Pu and U^{235} which makes it possible to obtain a negative temperature coefficient throughout the fuel lifetime, unlike the natural uranium

* Operated by Union Carbide for the A.E.C.

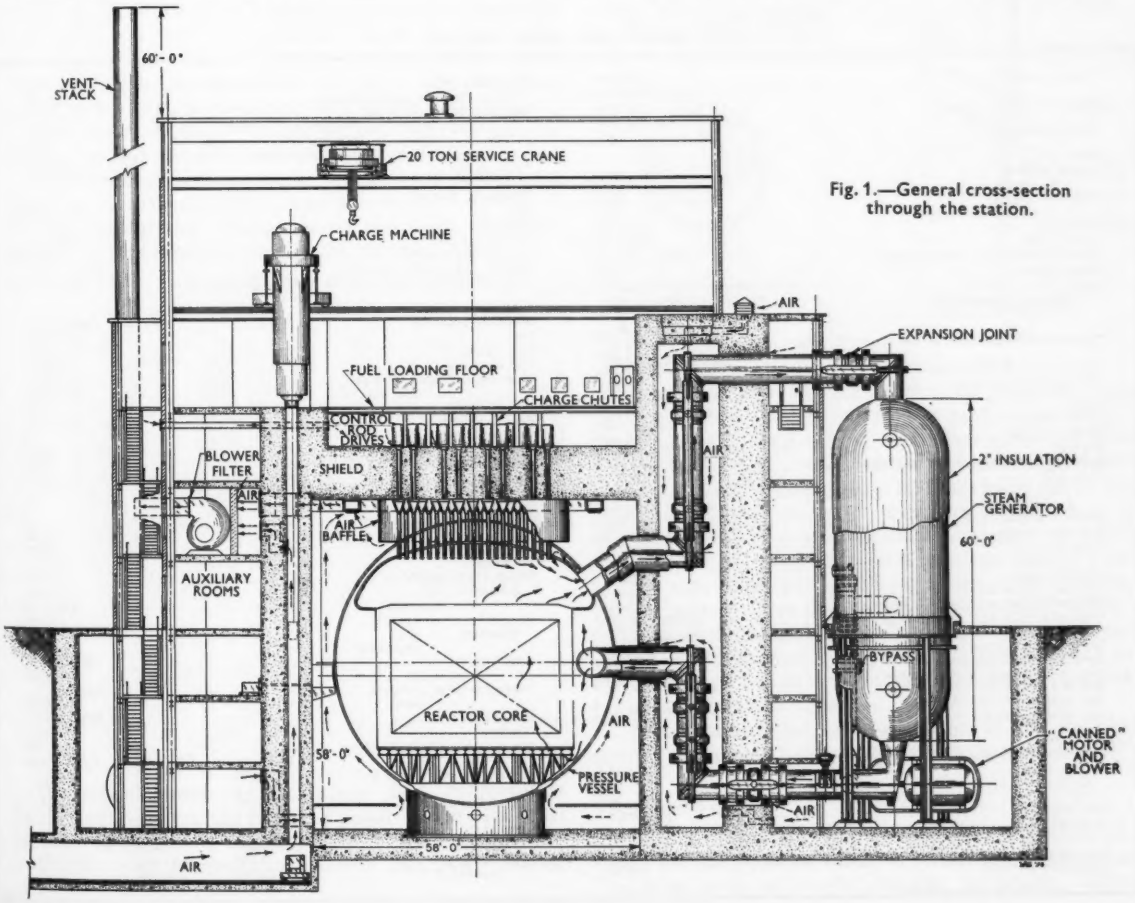


Fig. 1.—General cross-section through the station.

reactor where it is difficult to prevent a change to a positive temperature coefficient after irradiation corresponding to approximately 1,000 MWD/tonne.

Canning

The pros and cons on stainless steel canning were examined at some length. For high-temperature operations, Al and Mg were ruled out; zirconium would be rapidly embrittled by contaminants in helium; beryllium fabrication techniques are not yet considered to be adequate. The steel chosen was type 304 which has a composition (weight percentages) of 18 Cr, 8 Ni, 2 (max.) Mn, 0.08 (max.) C, and was considered relatively cheap and satisfactory from the point of view of minimum oxidation, neutron absorption, and stability. A further important consideration was that it was readily available commercially. A longer-term development programme is under way on alternative materials such as beryllium, impervious graphite, ceramics and iron-aluminium alloys.

Coolant Gas

While admitting that CO_2 is a suitable coolant up to 400°C, ORNL believes that at the temperatures planned for GCR2, interaction would be expected, causing graphite burn-outs, and corrosion of both fuel can and pressure vessel. Helium, in addition to its chemical inertness, has advantages in heat transfer properties and pumping power; its principal disadvantage is its high cost. Whether this would be a significant item in the overall power cost, would depend on the leak rate achieved, although it is calculated that a 1% leak would cost some $78,000 a year.

General Design

The design study covers a single reactor station with a thermal output of 687 MW and an electrical output of 252 MW (gross) and 225 MW net, with four shell-and-tube heat exchangers, the general arrangement being shown in Fig. 1.

The core is a 24-sided prism with an overall diameter of 35 ft, composed of 30 ft active core and 2 ft 6 in. thickness of reflector. The height of the core is 20 ft, with 2 ft 6 in. reflector thickness top and bottom, the total weight being 1,122 tons. There are 1,597 fuel channels, 345 of 3.45 in. dia., 400 of 3.25 in., and 852 of 3.05 in., on a square lattice of 8-in. pitch. The total thermal (2,200 m/sec) neutron flux is 5×10^{12} n/cm²,sec and the total excess reactivity 10%.

Fuel Elements

Since the thermal conductivity of uranium oxide is considerably lower than that of metallic uranium, the use of thick rod elements would result in overheating of the centres. While a thin annulus design would be ideal from a thermal point of view, present techniques for UO_2 fabrication will not give the necessary dimensional tolerances to minimize the gap between fuel and can, so the choice narrows down to a bundle of thin cylinders. The actual

Table 1. GCR2 Design Particulars

Thermal output	687 MW 2.34×10⁹ BTU/h
Electrical output, gross	252 MW
net	225 MW
Overall efficiency	32.8%
Core	
Height (active)	20 ft
(overall)	25 ft
Diameter (active)	30 ft
(across corners)	35 ft
Density	1.65 g/cm³
Total weight	1,122 tons
Graphite absorption cross-section	4.0 millibarns
Fuel channels	1,597
Lattice pitch (square)	8 in.
Diameter of fuel channels	345 at 3.45 in. 400 at 3.25 in. 852 at 3.05 in.
Temperature coefficient at 400°C per °C, max.	-14×10^{-5}
min.	-4×10^{-5}
Thermal flux (2,200 m/sec)	5×10^{12} n/cm²-sec
Total excess reactivity	10%
Fuel	
Enrichment	2%
Total uranium	150.8 tons
Burnup	7,350 MWD/t
Fuel element temperature coefficient	-4.7×10^{-5}/°C
Slug O.D.	0.75 in.
I.D.	0.32 in.
Length	0.5 in.
Internal temperature (max.)	2,200°F
No. per capsule	75
Capsule length	38.5 in.
O.D.	0.8 in.
Wall thickness	0.020 in.
Internal surface area	0.6375 ft²
Internal surface area, total for reactor	42,760 ft²
Internal surface heat flux, average	56,000 BTU/h-ft²
max.	96,000 BTU/h-ft²
Design max. surface temperature	1,200°F
Average surface temperature	1,000°F
Wt. of stainless steel per capsule	0.248 kg
No. of capsules per element	7
No. of elements per channel	6
No. of elements per reactor	9,582
Control	
No. of control rods	61
Length of rod	18 ft
O.D.	2 in.
I.D.	1.25
Out speed	8.48 in./min
In speed, slow	8.48 in./min
fast	84.8 in./min
Reactivity invested in rods	14.5%
Reactivity per rod	0.24%

Shielding	
Thermal neutron shield thickness	0.5 in.
Biological shield thickness	9 ft
Density of concrete	145 lb/ft³
Height	67 ft
Dia. across flats	76 ft
Total weight	23,400 tons
Pressure Vessel	
Dia.	50 ft
Thickness	3.25 in.
Working pressure	300 p.s.i.
Max. temperature	650°F
Weight of graphite support	75 ton (U.S.)
Total weight of vessel supports, thermal barriers, etc.	770.5 tons (U.S.)
Coolant	
Working pressure	300 p.s.i.a.
Flow	972 l./sec
Inlet temp.	460°F
Outlet temp.	1,000°F
Velocity, average cool pipe	100 ft/sec
hot pipe	161 ft/sec
I.D. of ducts	5 ft
Pressure drop	6.61 p.s.i.
No. of blowers	4
Motor h.p. per blower	6,000
Adiabatic efficiency	80%
Speed	3,580 r.p.m.

Heat Exchangers

No.			4
Height overall			60 ft
I.D.			20 ft
Thickness			2.75 in.
Steam drum length			21.5 ft
(Header) O.D.			28 in.
thickness			1.875 in.
Feedwater drum length			19.5 ft
(Header) O.D.			28 in.
thickness			1 in.
Steam pressure			950 p.s.i.a.
temperature			950°F
Feedwater inlet pressure			1,020 p.s.i.a.
temp.			325°F
Steam flow			505,000 lb/h
Gas flow			243 lb/sec
No. of tubes per exchanger			82
	Economizer	Evaporator	Superheater
Total length of tubing, ft	26,300	29,400	26,900
O.D., in.	1.5	1.75	2.375
Wall thickness, in.	0.12	0.135	0.25
Fins per foot	105.6	105.6	—
Fin O.D., in.	2.5	2.5	—
Thickness, in.	0.04	0.04	—
Area inside, ft²	8,280	11,580	12,400
outside, ft²	122,000	112,000	15,750

form taken is shown in Fig. 2; each fuel element has a nominal length of 40 in., and consists of seven cylindrical units or capsules.

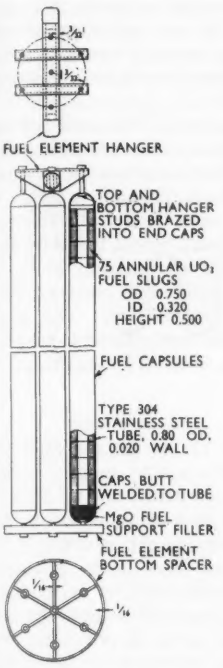

FUEL ELEMENT HANGER
TOP AND BOTTOM HANGER STUDS BRAZED INTO END CAPS
75 ANNULAR UO2 FUEL SLUGS OD 0.750 ID 0.320 HEIGHT 0.500
FUEL CAPSULES
TYPE 304 STAINLESS STEEL TUBE, 0.80 OD, 0.020 WALL
CAPS BUTT WELDED TO TUBE
MgO FUEL SUPPORT FILLER
FUEL ELEMENT BOTTOM SPACER

Fig. 2.—Arrangement of fuel element.

The capsules are of stainless steel tube, 0.8 in. outside diameter and 0.02 in. wall thickness with hemispherical ends machined from bar, having an integral stud for attaching the unit to the hanger and spacer top and bottom. The bottom stud has a hole drilled throughout its length for gas purging during assembly.

The fuel is in the form of annular slugs 0.75 in. o.d., 0.32 in. i.d., and 0.5 in. long. The process proposed is to compact the fine-grain oxide into briquettes, these afterwards being crushed and screened to produce granulated powder, which is then cold-pressed at 11 ton/in.^{2} and sintered in hydrogen for 1 hour at 1,750°C, this producing a slug with a density more than 94% of the theoretical.

Each capsule contains 75 slugs and two MgO end spacers compacted and sintered from refractory magnesia.

The seven capsules forming the complete fuel element are arranged in hexagonal form, and attached to a spacer at the bottom end and a hanger at the top, from which the element is supported by slots in the graphite (Fig. 3).

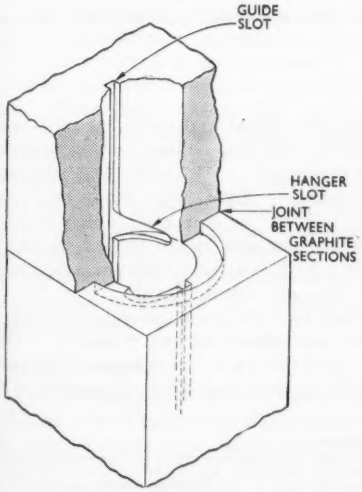


Fig. 3.—Part section through graphite block showing fuel element hanger slots.

The fuel elements are not finned. It is realized that finning could reduce the pumping power but it is felt that there is little point in considering it for material of comparatively poor thermal conductivity and high neutron absorption cross-section.

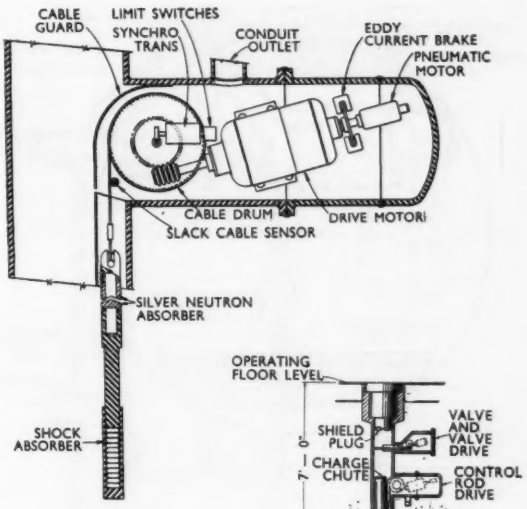


Fig. 4.—(Above) Detail of control rod and drive.

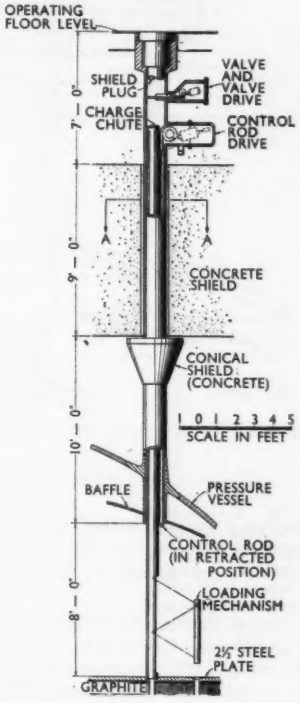
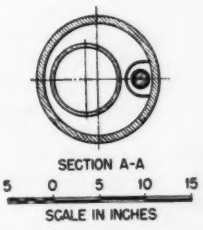


Fig. 5.—(Right) Section through charge chute.



Control Rods

Boron was ruled out for control rod purposes, because of dimensional changes due to high burn-up of boron and high operating temperature. Europium oxide and crystal-bar hafnium were considered too expensive, and hafnium sponge difficult to fabricate, so that the choice fell on silver. The control rods are hollow cylinders of silver 2 in. o.d., 1¼ in. i.d., and 18 ft long sheathed in stainless steel. There are 61 rods averaging 0.24% $\delta k/k$, the total reactivity vested in the rods being 14.5%. The rods are cable-operated by worm gearing from standard 60-cycle motors, which are contained within the pressurized area. An emergency speed of approximately 10× normal is provided by a small pneumatic motor on the electric motor shaft, operated by compressed helium (Fig. 4).

An interesting feature of the design is that the control rods and charge chutes occupy the same tube (Fig. 5).

Pressure Vessel

Considerable effort was devoted to the selection of the steel for the pressure vessel in reconciling the number of variables such as tensile strength, weldability, effect of

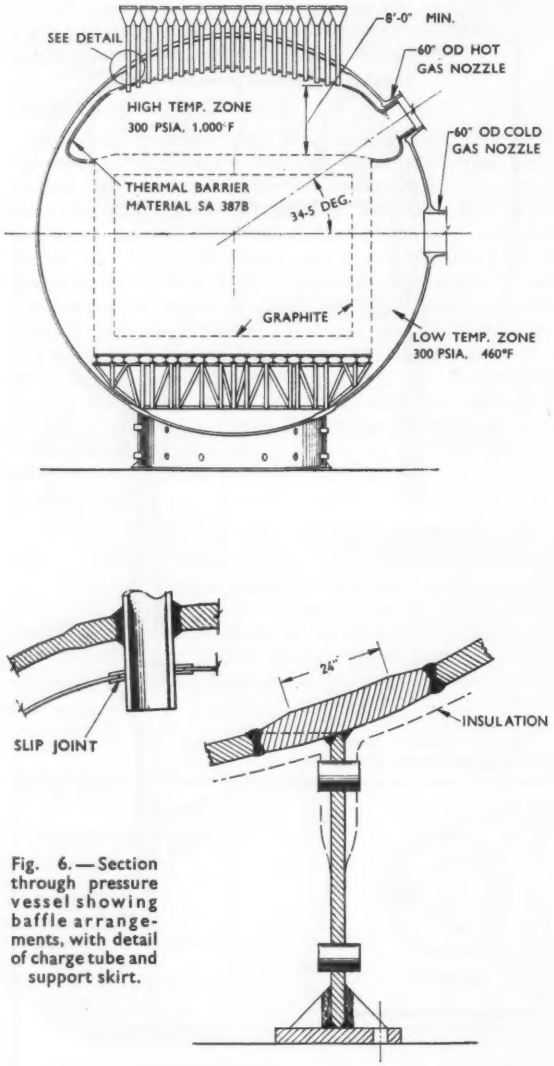


Fig. 6.—Section through pressure vessel showing baffle arrangements, with detail of charge tube and support skirt.

temperature, liability to brittle fracture, effect of irradiation, strain ageing and overall costs. Ease of welding was considered particularly important, in view of the number of penetrations requiring forgings for reinforcement. As a result of the analysis, SA212 Grade B, a plain carbon silicon steel was selected, and arrangements made to control the operating temperature, since the cost of steels for good strength characteristics at 700-1,000°F is high.

The pressure vessel is designed so that the entire surface is swept by the low-temperature inlet gas, keeping the temperature down to approximately 460°F at all power levels. This arrangement has advantages over external air cooling, in that it reduces heat losses, which would be excessive with cold air, and gives greater assurance of a uniform temperature distribution. It is effected by the provision of a baffle above the core, isolating the hot gas from the vessel walls; this construction is shown in Figs. 1 and 6. This, of course, involved the use of thermal sleeves between the outlet pipe and the pressure vessel to avoid the steep temperature gradients that would occur with an ordinary joint.

The vessel has an outside diameter of 50 ft, and a thickness of 3¼ in., the working pressure being 300 p.s.i. It is supported on a skirt 22 ft dia., which also directly transmits the core weight to the foundations through a series of radial trusses, which are carried on a thickened section of the pressure vessel shell, at the point where the skirt ring supports it. The skirt is insulated over the top 24 in., to allow expansion of the vessel without a corresponding movement of the skirt at the foundations. The gross weight of the vessel, including thermal barriers, graphite support, nozzles and insulation is some 775 tons (U.S.).

Gas Circuit

One of the interesting features of the gas circuit is the use of only one valve in each of the four loops. It was considered that gate shut-off valves could not be built in very large sizes to give absolute shut-off, and it was felt that it was impracticable to visualize the isolation of a steam generator while the system was under pressure. Furthermore, in the event of a steam leak, no valve could operate fast enough to prevent steam flow into the gas system, so that there seemed little point in providing two valves, and a single butterfly-type valve is provided in the cold leg of each circuit.

The gas ducting itself is of SA212B steel, as used for the pressure vessel, for the cold leg, and SA387B low-alloy steel for the hot leg, both being of 60-in. diameter. Vaned mitred joints are used at the right-angle bends.

The expansion joints have been designed so that loads due to pipe movements are carried by the hinge joints consisting of tension bars and reinforcing rings, and are not transmitted to the bellows proper. These are of stainless steel, provided with back-up rings to distribute deformation equally between the convolutions, and prevent collapse under pressure.

Blowers

A thorough analysis of capital and operating costs was carried out for seven different blower arrangements. Constant-speed arrangements with controlled by-pass included synchronous-motor drive with shaft seal and squirrel-cage motors "canned" or with shaft seal. Variable-speed drives investigated included steam turbine, squirrel-cage motors with both hydraulic and magnetic couplings, and Ward-Leonard types, all with shaft seals.

It was finally decided that the plain squirrel-cage motor, canned, without shaft seal offered the best prospects. The motor, of 6,000 h.p. at 3,600 r.p.m., is contained together with the blower within an enclosure 12 ft diameter × 24 ft

Table 2. Variation in Performance for Different Coolant Gases

Gas	Thermal output MW	H.p. per blower	Outlet temp. °F	Can temp. °F	Electrical output MW	
					Gross	Net
He	700	6,000	1,000	1,200	251	222
CO_2	700	8,000	880	1,200	231	197
H_2	700	3,000	842	980	226	206
H_2	700	2,050	1,020	1,200	251	234
H_2	990	3,000	1,004	1,200	355	331

long. A heat shield is provided between the blower and the motor, the motor vessel being kept down to 40°C (104°F) by a water cooler.

To facilitate starting of blowers and provide short-term flow adjustment a 30-in. by-pass is provided between the blower discharge and an intermediate point in the steam generator, the diameter of the pipe being chosen to give the same system resistance as the main circuit.

It is conceivable that the coolant selected might not be helium, in which case modifications might be necessary. Analyses of conditions for hydrogen and CO_2 have been carried out; results are summarized in Table 2.

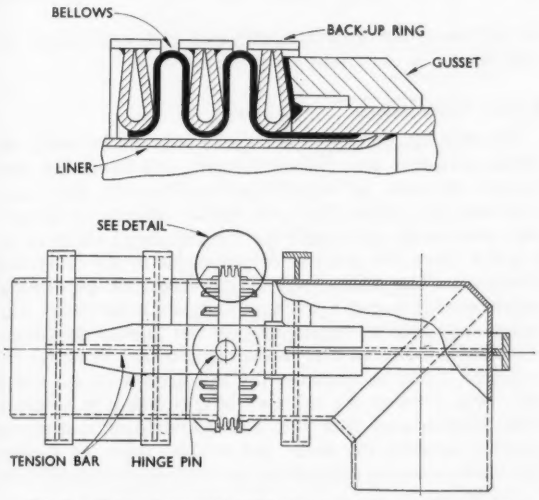


Fig. 7.—General assembly of bellows and detail of restraint.

It will be seen that if CO_2 were selected the blowers would need to be changed, as well as the motors.

Shielding

An interesting feature is the use of borosilicate glass ("Pyrex") as a neutron shield. Boron steel ⅛-in. thick would have sufficient boron but was considered not dimensionally stable under irradiation and non-weldable. Boron again is considered non-weldable. The Pyrex used is ½-in. thick, and is canned in sheet steel, a double layer of this material forming a neutron curtain around the graphite *inside* the pressure vessel. The top surface is covered by a layer of Pyrex tiles, also canned; the object of the canning is principally mechanical protection, since the glass itself is expected to be capable of taking some 10× the radiation damage to be expected over a 20-year period.

It is not expected that the reduction in thickness of the concrete shielding will offset the cost of this shield but it is felt that its use is more than justified by the reduction of thermal stresses in the concrete and heating in the pressure vessel.

Heat Exchangers

The primary object of the steam system studies was to provide a well-balanced simple system to produce power at near minimum cost. Although it was realized that some improvement in thermal efficiency could be obtained with a dual-pressure or re-heat cycle, it was decided that the additional complexities outweighed the possible advantages, and a simple superheat cycle was chosen to give not more than 12% moisture in the exhaust steam, and effort was concentrated on optimization of the major parameters, the principal problem being to match steam and helium circuits

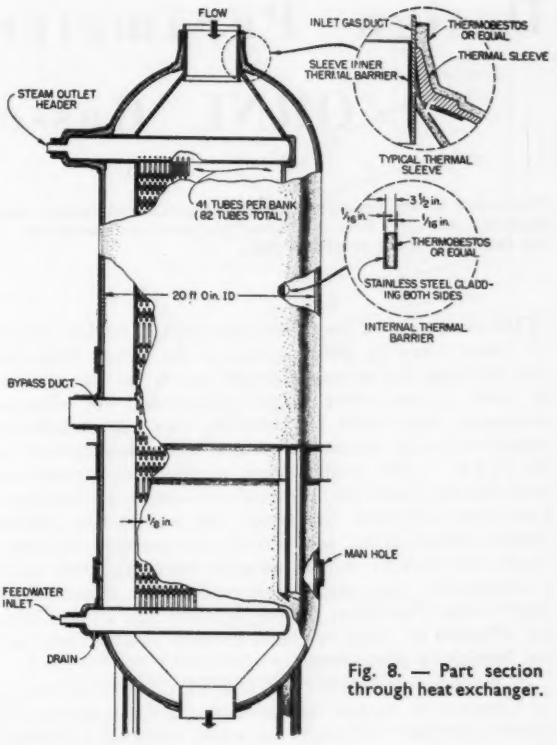


Fig. 8. — Part section through heat exchanger.

to give minimum power cost for the range 460°F-1,000°F selected for the reactor.

It was not possible, in the limited time available, to optimize the design in every way.

The four heat exchangers, or boilers, each generate 505,000 lb/h at 950 p.s.i.a., and 950°F. There are three stages of feedwater heating, the feedwater temperature being 325°F.

The design of the heat exchangers themselves is particularly interesting in that they are of the straight-through type, with *internal* headers top and bottom. This possessed the advantage of reducing to the minimum the number of shell penetrations. On the other hand, it hampered the design in that the number of circuits in parallel had to be the same in the economizer, boiler, and superheater sections, whereas the pressure drop in the boiler section is 15-30 times that in the economizer section, so that a larger tube diameter was necessary for this section. Furthermore, all joints being internal, are not readily accessible in case of leakage. However, a study of coal-fired boilers gave a figure of 15 leakages in 50,000 joints operating for a total of 1½ million joint-years of service. Furthermore, the experience of Calder which, with 35 times the number of joints of the ORNL design, had suffered no leakage in a year's operation, was a telling point.

Fig. 8 shows the general arrangement of a heat exchanger, with the internal headers. There are 82 tube circuits in parallel arranged with 41 tubes in each of two horizontal rows, the water flow being in opposite directions in adjacent rows. The material selected is a low-cost alloy containing 1% Cr and ½% Mo.

For the economizer and boiler sections, finned tubes were used with more than 105 fins per foot run, the fin thickness being 0.04 in. Further particulars are given in the appropriate section of Table 1.

(*For translations see page* 286.)

Design Parameters in the ORNL Gas-cooled Reactor Study

This article briefly reviews the enriched gas-cooled reactor study made by Oak Ridge National Laboratory from the nuclear and economic viewpoints. The engineering features are dealt with in the preceding pages.

THE evaluation of the Calder Hall-type of nuclear power plant made by Banks *et al.*[1] in the U.S.A. indicated that, although the technologies involved in the construction of such a plant were largely developed, the ultimate economics that could be foreseen were not sufficiently attractive for the system to receive active development in the U.S.A. The studies were confined to information available on Calder and although certain design modifications were proposed, the system did not receive intense detailed examination, and not all the possible improvements, for example in heat transfer, were exploited. Also a comparison was drawn essentially with conventional plant rather than other nuclear systems and at that time the influence of rising estimates in water reactor costs had not been fully appreciated.

In the summer of 1957 the U.S.A.E.C. were instructed by Congress to reopen the gas-cooled graphite-moderated reactor question and begin the active study of a Calder-type reactor. As a result the A.E.C. put out a request for proposals and from the 31 replies, selected Kaiser Engineers with ACF Industries as nuclear associates to undertake the work under the direction of the Idaho Operations Office. The original request called for a natural uranium fuelled reactor of 40 MW(E) capacity. At the same time, Oak Ridge National Laboratory undertook a more general study of a full-scale power reactor with the likelihood of slight enrichment much in mind. Kaiser's latterly also considered enrichment with sufficient thoroughness to conclude that the potentials of the enriched system were significantly greater than those of natural uranium and having submitted their first report are actively engaged on a more detailed study of an enriched oxide, CO_2-cooled reactor which is likely to lead to prototype construction at Idaho Falls.

The main differences between the two U.S. approaches concern the coolant (helium in the ORNL GCR2, and CO_2 in the K.E./ACF design) and the philosophy of gas circuit integrity. ORNL, influenced by their diffusion plant experience, propose an enclosed system—i.e. internal connections on the heat exchangers, minimum number of main duct valves, enclosed circulators, by-pass control, etc., whilst the Idaho philosophy can be classified as mid-way between Oak Ridge and the British. Both designs contemplate oxide fuel and stainless-steel cladding. Beryllium technology is not considered sufficiently far advanced and it is anticipated that increased element cost would more than offset the lower enrichment. The ORNL study[2] is not considered complete, not only in certain engineering details but in the optimization, as a lower final enrichment was envisaged and not until near the end of the study was it clear that an enrichment to at least 2% U^{235} would be desirable. Whereas stainless steel type 430 was initially chosen for the cladding material, the design is now predicated on the use of type 304. Relative cross-sections are such that 0.020 in. 430 steel is equivalent to 0.017 in. 304 steel. Nevertheless, the general arguments and conclusions are unlikely to be materially changed.

Lattice Calculations

Calculations on lattice constants were made using the world-consistent set of cross-sections, and compared with figures obtained in exponential experiments and those published for Calder Hall. It will be noticed in Table 1 that whereas the agreement for the calculated value of k_∞ is good, there are marked discrepancies in the individual constants. The Calder figures are based on exponential measurements and it is felt that each set is internally consistent and the k_∞ agreement is not merely fortuitous. The checks indicated that an overall accuracy of about 1% or better, could be expected for calculations of k_∞ and k (eff). Fig. 1 shows the influence of enrichment in a reactor with Magnox-clad fuel and fuel channels of a diameter midway between the inner and middle zones of Calder. The lowest curve is appropriate to the Calder reactor where $k_\infty = 1.065$.

Table 1. Comparison of Constants

	Computed	Calder Hall
η	1.342	1.266
ε	1.032	1.030
p	0.857	0.878
f	0.897	0.930
k_∞	1.065	1.065
R_C	0.825	0.85

When departing from a simple fuel geometry to the seven-rod cluster proposed in the GCR2 design,[3] it was necessary to find a satisfactory one-dimensional model. Two approaches were made. In the first, fuel was considered lumped as a single rod with all the cladding outside and in the second, the six outer rods were replaced by an annulus with half the cladding inside and half outside, the annulus being positioned so that the pitch circle of the rods divided the annulus into two equal volumes. Calculations of k_∞ showed little difference between the two methods but differences in the figures for resonance escape probability and thermal utilization factor led to the adoption of the annulus model.

In addition to the fuel-rod cluster incorporated in the engineering design, calculations were made on single UO_2 rods which showed the effect of cladding thickness on enrichment. Compared to an unclad natural uranium rod 0.040 in. to 0.060 in. stainless steel (type 430) requires an enrichment of 1.0% to 1.25% in U^{235} whilst for clusters 1% enrichment will accommodate 0.020 in. stainless-steel cladding. It became clear (Figs. 1 and 2) that increasing power density by reducing lattice pitch and compensating with enrichment was of only limited value. A factor of two would appear to be the economic limit. With a lattice

pitch smaller than the optimum, the decrease in resonance escape probability is the predominant effect of increased fuel-channel diameter, although in the region of maximum k_∞ this parameter has little influence on reactivity except through neutron streaming.

A comparison of Figs. 1 and 2 demonstrates the considerable reduction in conversion ratio for a given lattice pitch with increased U^{235} fuel content (for obvious reasons) but for a given multiplication factor a small amount of enrichment increases the conversion ratio. Where a system is optimized for power and fuel life represents a major cost parameter the second comparison is likely to be the more important.

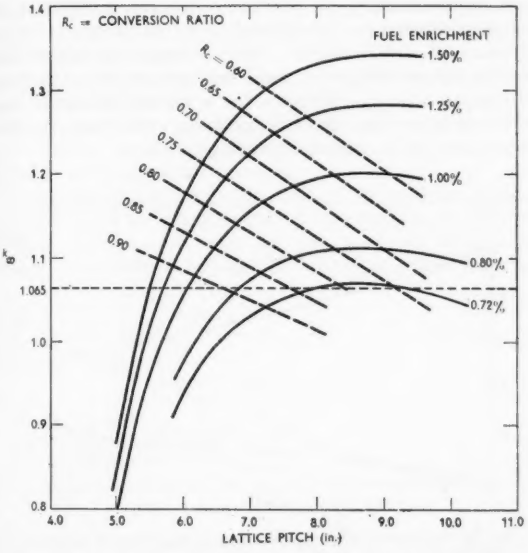


Fig. 1.—Effect of enrichment and lattice pitch on multiplication factor, Calder-type element, 4 in. channel.

Fuel Rods

Long life implies considerable fuel stability and a central hole for the accumulation of fission product gases had been suggested. Studies of the effect of this hole on reactivity suggest that a $\frac{5}{16}$-in. diameter hole in each rod, although causing a reduction in k of 0.9%, would be metallurgically justified. In a $\frac{3}{4}$-in. rod, the effect on multiplication factor is negligible with holes below 0.2 in. diameter rising steeply when this diameter is increased beyond 0.3 in.

Choice of fuel element is, of course, dominated by heat transfer and power density considerations. Larger diameter rods increase the volume of fuel in the core but decrease the surface to volume ratio and hence heat extraction efficiency. Calculations of multiplication factor against fuel/core volume ratio show for seven-rod clusters with rod diameters of 0.5 in., 0.75 in. and 1.0 in., volume fractions of 0.033, 0.047 and 0.055 for a k_∞ of 1.2. The ratio between these: 1.0/1.39/1.62 is reasonably constant over the range of multiplication factors likely to be met in practice. For the same rods, specific power densities under optimum conditions are in the ratio 1.0/0.77/0.59. The ratio of the product of these figures which gives the power available per unit core volume is 1.0/1.07/0.96. It would appear, therefore, that the seven-rod cluster of $\frac{3}{4}$-in. rods represents the maximum on a slowly varying curve. Other considerations also lead to the conclusion that a $\frac{3}{4}$-in. diameter rod falls on a broad maximum on the optimization plot.

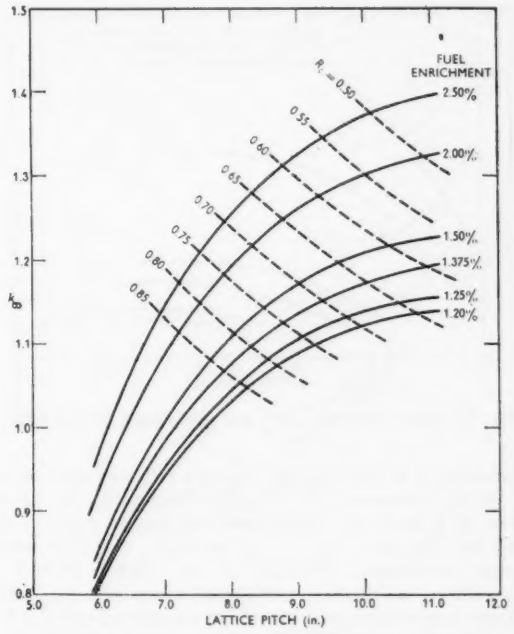


Fig. 2.—Effect of enrichment and lattice pitch on multiplication factor. Seven uranium oxide rods $\frac{3}{4}$ in. dia.

Geometric Factor

Although in general terms the larger the vessel and core the smaller is the resultant capital charge/kWh, for a given power output, the smaller the core, the less are the capital charges. The minimum size is determined by the value of k(eff) which can be calculated by the standard relationship

$$k(\text{eff}) \doteq k_\infty/(1+M^2B^2)$$

where M^2B^2 is the sum of the products of the axial migration area and axial buckling and the radial migration area and radial buckling. In Fig. 3 the computed value of M^2B^2 is shown for a seven-rod $\frac{3}{4}$-in. dia. cluster with 2%

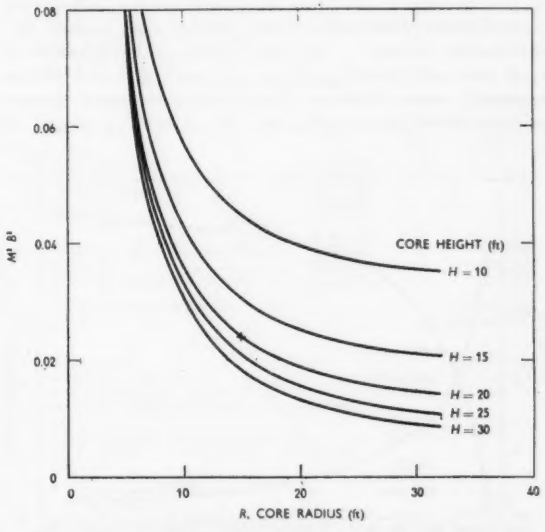


Fig. 3.—Effect of core height and diameter on neutron leakage.
(Seven $\frac{3}{4}$ in. rods in $3\frac{1}{2}$ in. hole, 0.018 in. cladding, 8 in. lattice and 2% enrichment.)

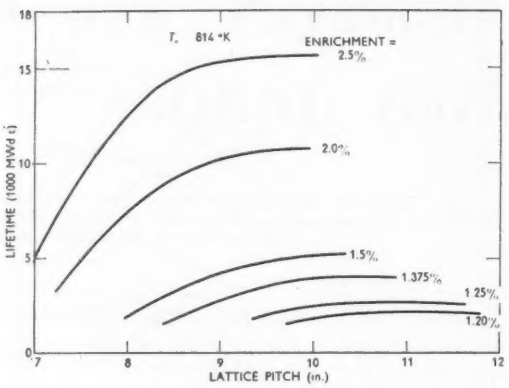


Fig. 4.—Effect of lattice pitch and enrichment on fuel life.

enrichment in a 3¼-in. channel against reflected core radius for various values of core height. Decreasing the height below 20 ft leads to a significant reduction in k(eff) in the same way that for a core radius less than, say, 10 ft losses become exorbitant. Leakage of the ORNL GCR-2 is indicated by the cross. With the same fuel assembly, leakage is minimum over the range of lattice pitch 6-8 in., the shape flattening with increasing enrichment and the centre of the minimum increasing from 6-7 in. as U^{235} content changes from 0.7 to 3%

Burn-up

In any reactor system, ultimate power costs are strongly dependent upon fuel life. This is particularly true when ceramic fuel elements are involved due to the high fabrication cost. Loop experiments have indicated that from the metallurgical standpoint an irradiation of at least 10,000 MWd/t can be accommodated and providing reactivity can be maintained, this figure can form a reasonable basis for estimation. In assessing the Oak Ridge Gas Cooled design the core was considered under three irradiation conditions: batch loading with core of uniform power density; batch loading, non-uniform power density; power density adjusted by fuel cycling to give uniformly graded fuel irradiation. Certain assumptions were made, notably slow neutron flux distribution within a cell was assumed independent of irradiation, self shielding of the 1 eV resonance of Pu^{240} was neglected and effective cross-sections were deemed independent of lattice pitch over the interesting range. At the conclusion it was found that neutron leakage had been overestimated by an amount equivalent to 1% in k and it was suspected that fission product poisoning had also been overestimated.

Fig. 4 illustrates the results of calculations made assuming batch loading, uniform exposure, with a mean neutron temperature of 541°C and demonstrates the necessity for significant enrichment. If these curves are re-drawn in terms of conversion ratio, the differences between optimizing for plutonium production and power become clear. Fuel life increases with conversion ratio significantly from R_e=0.5 to R_e=0.6, only slowly from R_e=0.6 to R_e=0.7 and then decreases markedly as R_e increases to 0.8. Fig. 5, although referring to a lattice pitch of 8.2 in. substantially indicates the build-up of plutonium isotopes in the adopted design compared to the original U^{235} fuel content. At an exposure of 10,000 MWd/t, Pu^{239} is almost in equilibrium but the concentration of the other isotopes is continuing its regular change. Whereas for a natural uranium feed k(eff) initially rises during operation, reactivity steadily decreases with an enriched loading.

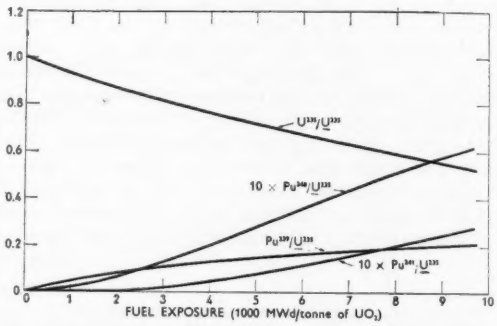


Fig. 5.—Variation of isotope content in fuel with irradiation.
(Seven ¾ in. dia. rods, 3¼ in. channel, 8.2 in. lattice, 0.018 in. cladding, 2% enrichment, T_n=814°K.)

If uniform irradiation across the core cannot be assumed, it is estimated that the lifetime is reduced by a factor roughly equal to the maximum/average power density ratio, say, 1.4 to 2 but if continuous loading is adopted a gain of about two could be expected. In the reference design (Fig. 4) the life is calculated to be something over 7,000 MWd/t for batch loading (uniform irradiation) whilst cycling could increase this to 15,000 MWd/t. Taken in conjunction with the fuel rating—5 MW/t it is clear that the life figure could be in the region of 10 years, which approaches the reactor amortization period. Really continuous loading which would necessitate the provision for charge and discharge under power is unnecessary as shown in Fig. 6 where the effect of regular batch loading is plotted against lifetime. If 10% of the fuel is changed at yearly intervals, the life is practically the same as would be obtained with continuous cycling. Such long life does, however, raise the problem of attaining equilibrium as start-up period represents such a major fraction of reactor life. No satisfactory solution has yet been offered and as estimates of the practical effect of cycling could not be placed on a sound basis, cost estimates have been made assuming bulk batch loading.

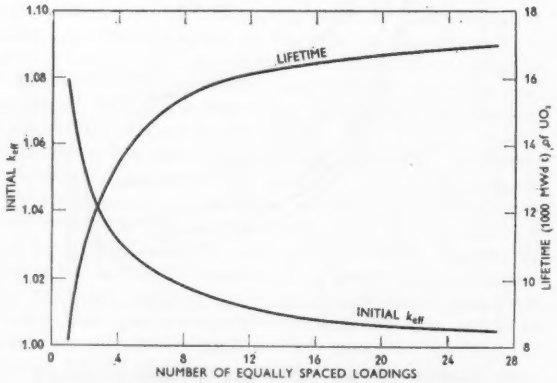


Fig. 6.—Effect of staggered loading on fuel lifetime.
Conversion ratio 0.70 for one loading, other conditions as Fig. 5.)

Temperature Coefficient

In addition to change of reactivity with fuel life, the change with temperature at various stages of burn-up assumes considerable significance when the safety of a

reactor system is being considered. The temperature coefficient can be broken down into components which can be calculated separately and cross-checks made; for example, Harwell figures were used in the cross-section coefficient and the Doppler broadening was related to measurements made on the Brookhaven reactor. For the GCR2 design it was assumed that the effect of fuel temperature varied linearly with the neutron temperature from $\theta_f = 760°C$ when $\theta_n = 541°C$ to $\theta_f = \theta_n = 20°C$.

To summarize the individual results, it was concluded that for the various coefficients:—

(1) the fast fission is always negative and small;

(2) the resonance escape probability is always negative independent of exposure growing more negative with increasing temperature;

(3) the thermal utilization factor is always positive increasing with exposure;

(4) the neutron yield is always negative growing more negative with exposure;

(5) the geometric factor is always negative and small;

(6) fission product poisoning changes from negative to positive as temperature increases.

Computation for the Calder Reactor showed the moderator coefficient to become positive at exposures over 1,000 MWd/t, as expected, but for the enriched design the coefficient remained negative at all temperatures and fuel

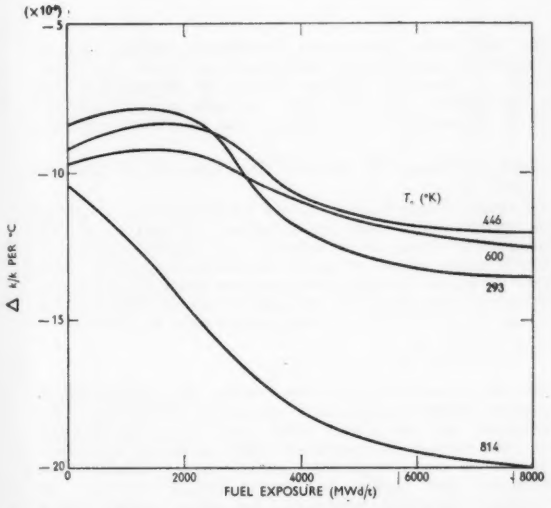


Fig. 7.—Effect of fuel exposure on temperature coefficient of reactivity.

exposures, initially showing a rise and then becoming more negative with increased burn-up. For a neutron temperature of 540°C the trend is continuously more negative with increasing exposure. It is suggested that the influence of Pu^{240} concentration is responsible for the general downward turn at exposures between 2,000 and 4,000 MWd/t. Fig. 7 gives the total moderator temperature coefficient of reactivity against exposure at four neutron temperatures.

Economics

Calculations on the absolute cost per kWh when no constructional or operational experience is available are invariably subject to a considerable error margin, but without such assessments the potential value of a system cannot be estimated and the gas-cooled reactor, because of the largely known technologies involved is probably more

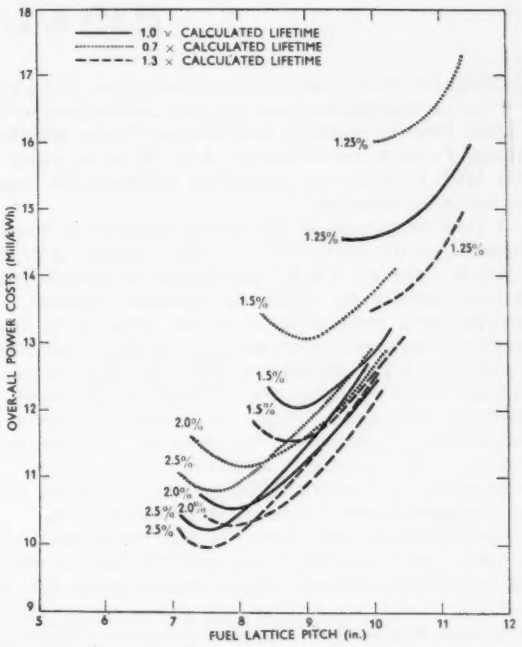


Fig. 8.—Effect of lattice pitch on overall power costs for various enrichments.

amenable to a theoretical treatment than certain other systems. The final figure derived for the ORNL GCR2 of capacity 225 MW(E), is a little over 10 mill/kWh which compares favourably with, for example, the PWR. Details are given in Table 2.

There seems little doubt that on the basis of the ORNL study and the K.E./ACF study a building programme for an enriched-uranium gas-cooled graphite-moderated reactor will be initiated and these preliminary evaluations indicate that the project will be pursued with vigour. Already there is considerable enthusiasm in the U.S.A. (and within the A.E.C.) for such a project.

REFERENCES

1. Banks, W. F., *et al.*, U.S.A.E.C. Reports, 1957, NAA-SR-1833-1955.
2. U.S.A.E.C. Report, ORNL 2,500.
3. *Nuclear Engineering*, 3, 277. July 1958.

Table 2. Power Costs

	Capital cost $	Annual rate %	Annual cost[1] $
Fixed costs:			
Reactor plant	47,904,700		
Contingency[1]	7,927,500		
General expense	7,615,000		
Design cost	2,510,000		
	65,957,200	14	9,234,000
Fuel element fabrication at $30.90/kg	4,230,000	14	592,000
Uranium fuel	30,000,000	4	1,200,000
Construction charges[2] at 6% for 1.5 y	5,936,100	14	831,000
Total annual fixed costs			11,857,000 =7.52 mills/kWh

	Annual cost $	Cost (mills/kWh)
Operating costs:		
Cost exclusive of fuel	1,400,000	0.89
Fuel burn-up less Pu credit at $12/g	1,310,000	0.83
Fuel element replacement fabrication at $30.90/kg U	822,000	0.52
Spent fuel recovery (multipurpose plant)	423,000	0.28
Fuel in process outside reactor at 13% of inventory	136,000	0.10
Total operating cost	4,091,000	2.62
Total power cost		10.14

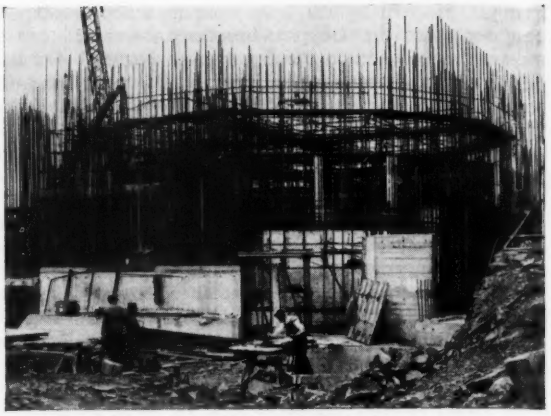
[1]Allowing for escalation costs during construction, the total annual fixed charges become $13,321,200, which corresponds to a total power cost of 11.12 mills/kWh.
[2]No construction charge is made against fuel-element fabrication because of the short time between fabrication and use.

HINKLEY POINT

HINKLEY POINT power station, the subject of the pull-out on the opposite page, is under construction by the English Electric—Babcock and Wilcox—Taylor Woodrow Atomic Power Construction Co., Ltd. With an output of 500 MW, it enjoys the distinction of being the largest station so far designed.

A brief description of the reactor appeared in *Nuclear Engineering* (October, 1957, p. 423), shortly after the C.E.G.B. (then the C.E.A.) had placed the contract, and various methods by which the increased capacity was achieved were outlined in the article. One of the more interesting features concern the steps taken to limit creep, which allows the designer to raise operating pressures without either increasing the thickness of the vessel or employing high-tensile alloys, by reducing the operating temperature of the sphere by insulation and controlled cooling. The principle involved is, of course, the same as that outlined for GCR2 on page 280 of this issue, but the method used is considerably less elaborate.

The preliminary civil work has been considerable, and includes a sea wall 3,000 ft long and 18 ft high, as well as the more usual approach roads. Access to the site was not complete until December, 1957. It is expected that the first reactor will go on load in mid-1961.



Erection proceeding on the first reactor.

Pages 277-281

L'Etude du projet du Réacteur Américain Refroidi à Gaz GCR2

L'Etude complète du projet du réacteur GCR2 refroidi à gaz a récemment été rendue publique, sous la forme d'un rapport, par le Laboratoire Nationale d'Oak Ridge. Parmi les nombreuses caratéristiques intéressantes on note l'emploi du combustible enrichi, sous la forme de bioxyde d'uranium, l'emboîtement par l'acier inoxydable, le refroidissement à l'hélium, un brûlage de plus de 7000 MWD/t, et l'emploi du verre "Pyrex" comme protecteur neutronique.

Der Studien-Entwurf für den Amerikanischen gas-gekühlten Reaktor GCR2

Ein vollständiger Studien-Entwurf für einen gas-gekühlten Reaktor GCR2 ist kürzlich vom Oak Ridge National Laboratory in Gestalt eines Berichtes der Oeffentlichkeit vorgelegt worden. Unter den vielen interessanten Einzelheiten befinden sich die Verwendung angereicherten Brennstoffs in Gestalt von Urandioxid, die Benutzung rostfreien Stahles für Brennstoff-Hülsen, Helium-Kühlung, eine Brennziffer von mehr als 7000 MWD/t und die Verwendung von "Pyrex" Glas als Neutronenschutz.

Estudio del Diseño del Reactor Americano GCR2 Enfriado por Gas

El estudio completo de un reactor GCR2 enfriado por gas ha sido emitido recientemente por el Laboratorio Nacional de Oak Ridge, en la forma de un informe. Las muchas interesantes características incluyen el uso de combustible enriquecido, en la forma de dióxido de uranio, envasamiento con acero inoxidable, enfriamiento con helio de un quemado de más de 7000 MWD/t, y el uso de vidrio "Pyrex" como un protector neutrónico.

Pages 282-285

Calculs de Conception du GCR2

Tandis que les ingénieurs du Kaiser en collaboration avec les "Industries ACF" continuaient leurs recherches sur un réacteur refroidi à gaz d'uranium naturel et modéré à graphite, ORNL entreprenait une étude plus générale afin de déterminer la valeur du léger enrichissement. Ces études basées sur un élément de combustible revêtu en acier inoxydable, démontrent qu'un enrichissement d'au moins 2% est nécessaire. Ce chiffre n'est pas définitif car, au début, on pensait qu'un enrichissement plus bas serait nécessaire et 2% est près de la limite la plus élevée de la série examinée. Les calculs de treillage furent comparés aux résultats enrégistrés sur les expériences exponentielles et à Calder Hall. Ceci indique qu'un treillis de 8 in. (203,2 mm) est souhaitable augmentant la densité de puissance par une réduction du pas, ce qui est sujet à la "loi du rendement non proportionnel." Avec un enrichissement de 2%, le coefficient de température est négatif durant tous les stades du brûlage devenant plus négatif en températures neutroniques dépassant 500°C.

Berechnungen für den Entwurf des GCR2

Während die Ingenieure von Kaiser in Gemeinschaft mit ACF Industries ihre Studien an einem mit natürlichem Uran beschickten, gasgekühlten und mit Graphit als Moderator arbeitenden Reaktor durchführten, unternahmen ORNL eine mehr allgemeine Untersuchung, um den Einfluss einer leichten Anreicherung zu bestimmen. Auf der Grundlage von Brennstoffelementen in Hülsen von rostfreiem Stahl ergaben die Untersuchungen, dass für beste Ausnutzung mindestens eine zweiprozentige Anreicherung erforderlich ist. Dies ist keine endgültige Zahl, denn man hatte anfangs geglaubt, dass eine geringere Anreicherung nötig sein würde, und 2% liegt in der Nähe der oberen Grenze der der Prüfung unterzogenen Werte. Gitterberechnungen wurden mit Messresultaten von exponentiellen Versuchen und von Calder Hall verglichen. Das Ergebnis war, dass ein 8 Inch Abstand im Gitter erwünscht ist, da ein Zuwachs in der Energiedichte mittels einer Reduktion des Abstandes dem Gesetz des immer kleiner Werdens des erzielbaren Gewinnes unterliegt. Bei einer zweiprozentigen Anreicherung wird der Temperatur Koeffizient in allen Stadien des Verbrennungsprozesses negativ und wird noch stärker negativ in Neutronen-Temperaturen, die 500°C übersteigen.

Cálculos de Diseño del GCR2

Mientras que los ingenieros de Kaiser, en asociación con la "ACF Industries" estaban llevando a cabo sus estudios sobre un reactor enfriado a gas de uranio natural y moderado a grafito, ORNL emprendió un estudio más generalizado para determinar el valor de escaso enriquecimiento.

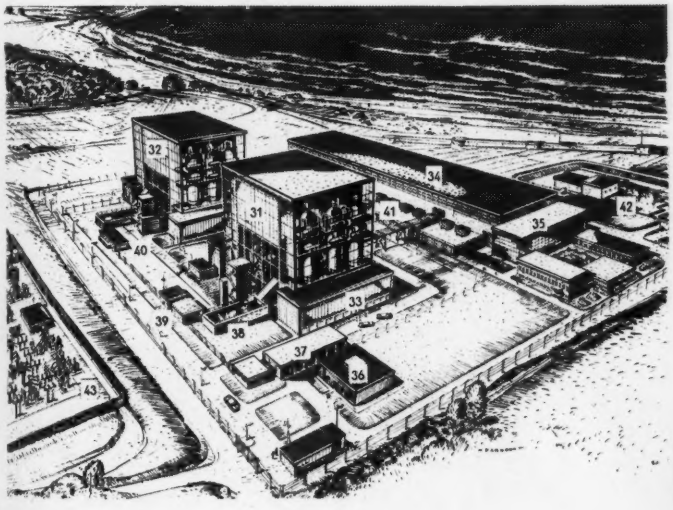
Basadas en un elemento de combustible revestido de acero ioxidable, los estudios de optimización indican que se necesita por lo menos un enriquecimiento del 2%. Esta no es una cifra final, ya que incialmente se creyó que sería necesario un enriquecimiento más reducido y el 2% queda cerca del límite superior de la gama examinada. Los cálculos de enrejado fueron comparados con resultados medidos en experimentos exponenciales en Calder Hall. Esto indica que un paso de enrejado de 8 in. (203,2 mm.) es deseable, siendo que el aumento de la densidad de potencia por una reducción del paso está sujeto a la ley de rendimiento no proporcional. Con el 2% de enriquecimiento, el coeficiente de temperatura es negativo en todas las etapas de quemado, volviéndose más negativo en temperaturas neutrónicas más allá de 500°C.

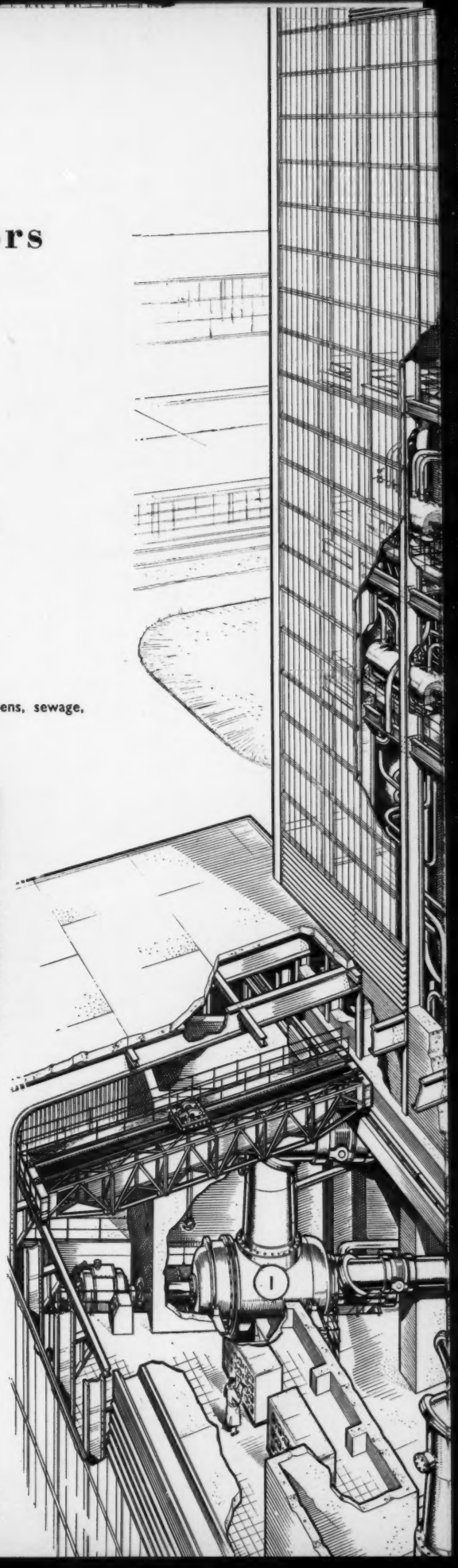
The World's Reactors

No. 19 Hinkley Point Power Station

KEY

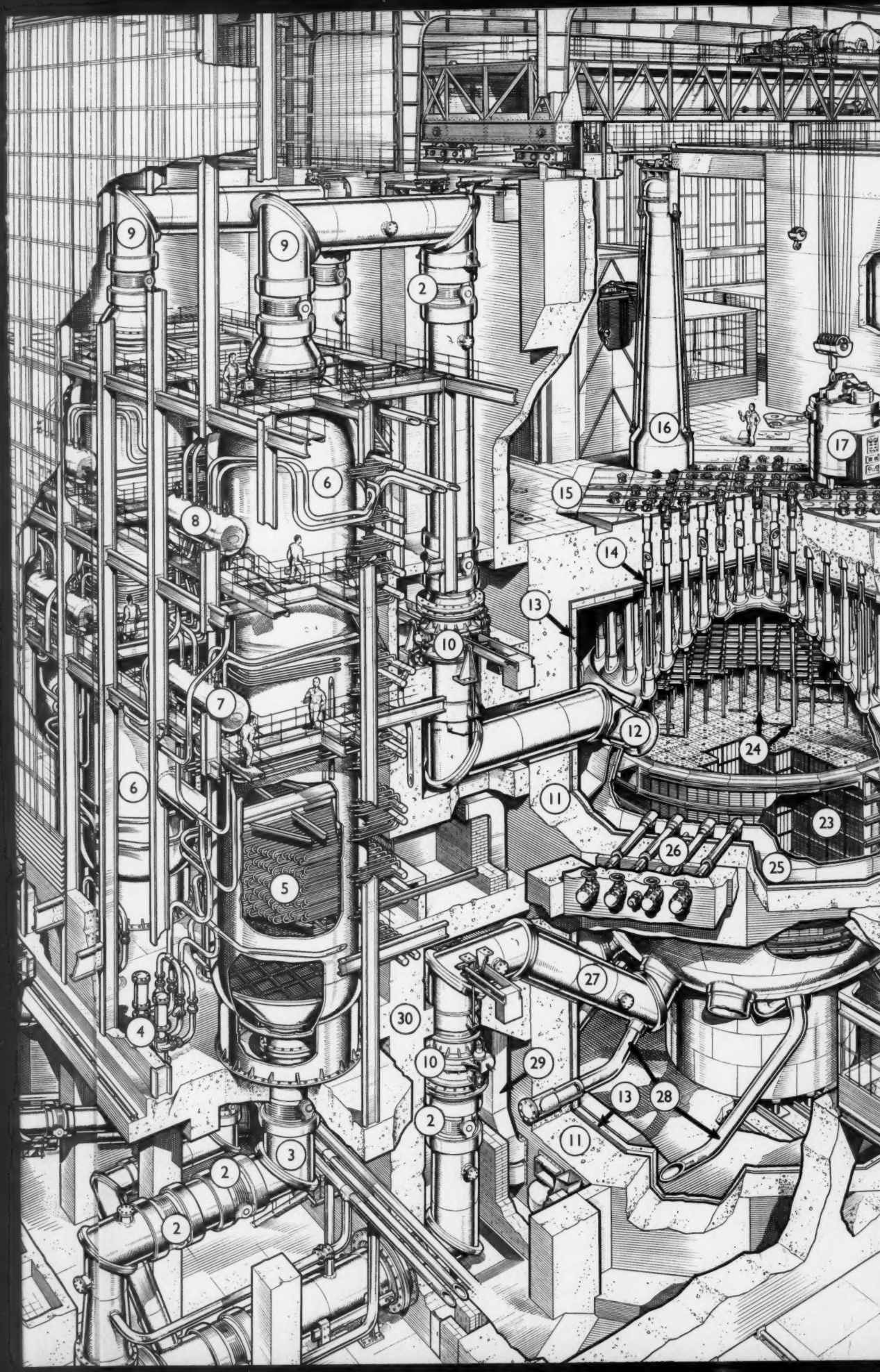
1. Blowers
2. Expansion bellows
3. Gas outlet from heat exchanger
4. Circulating pumps
5. Stud-tube elements
6. Heat exchangers (six per reactor)
7. L.P. steam drum
8. H.P. steam drum
9. Gas inlet to heat exchanger
10. Main-gas valves
11. Main biological shield
12. Gas outlet from reactor
13. Thermal shield
14. Charge tubes
15. Charge floor
16. Hole-preparation machine
17. Charge—discharge machine
18. Emergency discharge chute
19. Spent fuel element skip hoist
20. Cooling pond
21. Storage skips and grid
22. Skip loading bays
23. Graphite core
24. Control rod
25. Pressure vessel
26. Gas monitoring pipes
27. Gas inlet to reactor
28. Ducts for debris removal
29. Shield cooling ducts
30. Secondary biological shield
31. Reactor No. 1
32. Reactor No. 2
33. Blower house
34. Turbine house
35. Workshop
36. Diesel house
37. Fuel store
38. Irradiated element pond
39. Laundry
40. Decontamination
41. Control block
42. Pump house, forebay screens, sewage, etc.
43. Outdoor sub-station





Under construction by the English Electric, Babcock & Wilcox, Taylor Woodrow Atomic Power Construction Co., Ltd.

Drawn by Giles and reproduced by courtesy of Babcock and Wilcox, Ltd.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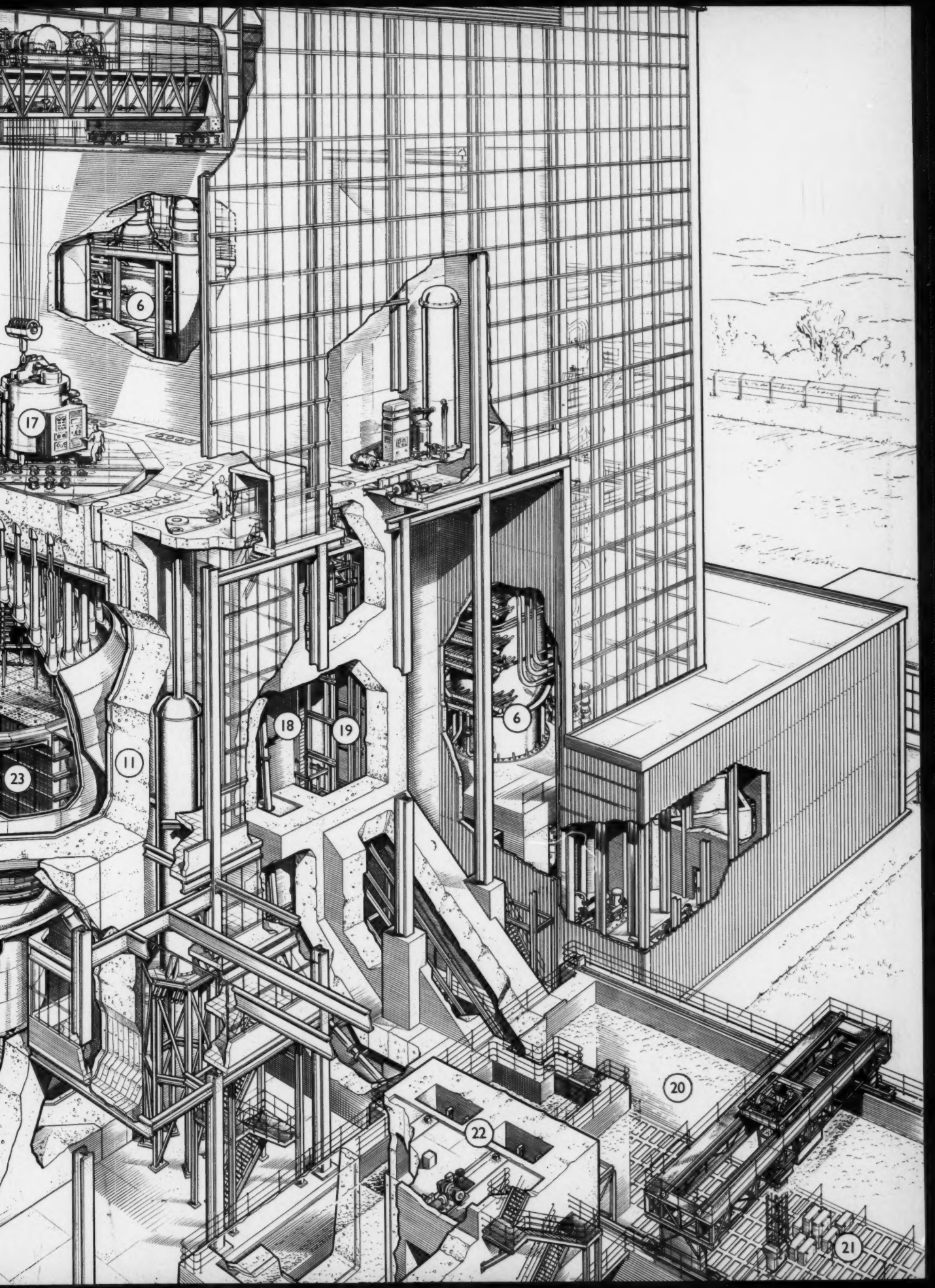
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The World's Reactors

No. 19 HINKLEY POINT POWER STATION

(Provisional Data)

TYPE:	Thermal heterogeneous.
PURPOSE:	Power production.
LOCATION:	Hinkley Point, Somerset.
OPERATION:	Access to Site: December, 1957. First reactor on load: mid-1961. Second reactor on load: end of 1961.
CAPACITY:	Station installed capacity: 551 MW + 99 MW auxiliaries. Guaranteed net output: 500 MW. Reactor heat ratings: 966 MW each.
FUEL:	Material: natural uranium. Dimensions: approx. $1\frac{1}{8}$ in. diameter, 36 in. long. Density: 18.7 g/cm³. Weight of U per reactor: 370 tonnes. Number of elements per channel: eight. Number of fuel-element channels: 4,500. Mean diameter of channels: 3.85 in.
CANNING:	Material: magnesium alloy, A.12. Construction: machined or extruded extended surface. Method of element support: stacked.
MODERATOR:	Material: graphite. Core size: 49 ft dia. × 25 ft high. Total weight per reactor: approx. 3,500 tonnes. Method of support: ball bearings.
LATTICE:	Regular square, $7\frac{3}{4}$ in. pitch.
CONVERSION:	0.85.
BURN-UP:	Minimum 3,000 MWD/tonne.
CONTROL:	Number of channels per reactor: 120. Diameter: as fuel elements. Control rods: 108. Shut-off: 12. Drive: variable-frequency induction motors.
SHIELDING:	Biological: concrete. 7 ft main, 4 ft secondary. Cooling: induced draught, air.
PRESSURE VESSEL:	Material: silicon-killed boiler-plate. Shape and dimensions: sphere 67 ft dia. Thickness of shell: 3 in. nominal. Support: skirt 30 ft dia.
COOLANT:	Carbon dioxide at 185 p.s.i. Inlet temperature: 180°C. Outlet temperature: 375°C. Number of ducts: six inlet and outlet. Diameter of ducts: 6 ft 6 in. Mass flow: 10,000 lb/sec.
PUMPING:	Number and type: six axial blowers. Drive: variable-frequency motors fed from variable-speed auxiliary turbo-alternator.
BOILERS:	Number per reactor: six. Main shell dimensions: 21 ft 6 in. dia. × 90 ft long. Element construction: stud tubes. H.P. steam conditions: 650 p.s.i. (685°F). L.P. steam conditions: 180 p.s.i. (670°F). Feed temperature: 160°F. Evaporation: 460,000 lb/h.
TURBO-ALTERNATORS:	Number and type: six impulse-reaction. Maximum continuous rating: 93.5 MW. Speed: 3,000 r.p.m. Generator voltage: 13.8 kV.

Data sheets in this series already published in "Nuclear Engineering" are:

No. 1. *BEPO* (*April*, 1956)
No. 2. *CP5* (*May*, 1956)
No. 3. *NRX* (*June*, 1956)
No. 4. *DIMPLE* (*August*, 1956)
No. 5. *ZEUS* (*September*, 1956)
No. 6. *CALDER HALL* (*October and December*, 1956)
No. 7. *RUSSIAN 5 MW* (*November*, 1956)
No. 8. *DIDO* (*January*, 1957)
No. 9. *THE SOUTH OF SCOTLAND ELECTRICITY BOARD STATION* (*February*, 1957)
No. 10. *BERKELEY POWER STATION* (*March*, 1957)
No. 11. *BRADWELL POWER STATION* (*April*, 1957)
No. 12. *DOUNREAY FAST REACTOR* (*June*, 1957)
No. 13. *EBWR* (*July*, 1957)
No. 14. *RWE* 1 (*September*, 1957)
No. 15. *LIDO* (*November*, 1957)
No. 16. *PLUTO* (*April*, 1958)
No. 17. *MERLIN* (*May*, 1958)
No. 18. *G*1 (*June*, 1958)

The British Electric Power Convention

OUTLOOK FOR GENERATION

C.E.G.B. Policy Outlined by Sir Christopher Hinton

(Abstract of paper "The Development of Nuclear Energy for Electricity Supply in Great Britain")

IN the United Kingdom, impelled by economic conditions, industrial power from nuclear energy has been a prime objective and defence requirements which were the basis of the initial programme have been orientated towards industrial power applications. The design and successful operation of the Calder Hall reactors gave rise to a great sense of national relief and a feeling that a firm foundation had been laid for a successful programme. However, when programmes have been evolved in an atmosphere of optimism, fundamental problems may become submerged and only reappear during the development of the programme; it is wise after a reasonable lapse of time to sit back and review the overall field.

The 1955 White Paper programme which called for the construction of 1,800 MW electrical capacity by 1965—equivalent to an annual coal consumption of 5 million tons—was thought to be a reasonable compromise between the serious long-term coal shortage and the realization that nuclear power was still untried. Initially it appeared that both graphite and uranium would present a raw materials problem. It was anticipated that power costs would be in the region of 0.6 d/kWh, a figure which allowed for a plutonium credit of about 0.35 d/kWh. The minimum value which could rightly be assigned to plutonium credit was the cost of the equivalent quantity of U^{235} bought as natural uranium less the cost for chemical treatment of irradiated fuel elements to extract the plutonium. The maximum value would be that of the equivalent quantity of U^{235} extracted from natural uranium in a diffusion plant.* In addition the assumption was made that a burn-up of 3,000 MWd/t could be achieved in the fuel elements.

In March, 1957, the programme was expanded and the target for 1965 lifted from the initial level of 1,500/2,000 MW to a level of 5,000/6,000 MW. Research into plutonium burn-up figures and the fast reactor had by this time shown that plutonium credit prices at the level originally set could not be justified and in addition the "scarcity value" was reduced because the U.S.A. had decided to make available considerable quantities of enriched uranium through the International Agency. At the same time, capital costs as shown by the C.E.A. tenders were somewhat lower than expected, but not sufficiently, to offset the reduced plutonium credit figure of 0.07 d/kWh. The estimated overall cost/kWh sent out had risen over the months from 0.6 to 0.66 pence. Fuel-element life still remained an unknown quantity and the proper figure can only be determined by operational experience.

Effect of Load Factor

The costs discussed so far have assumed a high load factor. Because of their high capital cost it is obviously wise to use nuclear power stations in this way, but it is a privilege which cannot be enjoyed indefinitely, unless system load factors are considerably increased. Minimum continuous load at present is only about 3,000 MW in the U.K. occurring at night, during week-ends in the summer. This, in effect, represents the base load on the system. Fig. 1 shows the estimated growth of the night load together with the forecast of the maximum nuclear capacity for the period 1960-1970. Beyond 1966 the total nuclear capacity will exceed the anticipated night load and therefore if full output is available load factor must be reduced during week-ends in the summer. After 1969 if nuclear stations have an availability of 100% some will be required to reduce output at night, even during the week. If a planned availability of 75% is assumed then reduction of load during summer week-ends will still be necessary after 1969.

In these circumstances, nuclear power can only continue to compete if the capital cost has been considerably reduced and this reduction must have been achieved by 1966 because it is at that date that the plants will be ordered and designed. Although further engineering developments are possible an ultimate

Fig. 1.—Loads available for nuclear generation, summer week-end. Full line, maximum, and dotted line available nuclear capacity. Chain-dotted line shows the night load available.

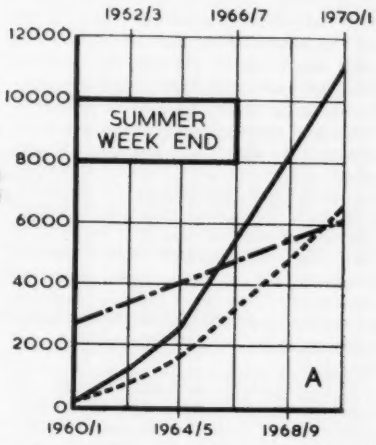
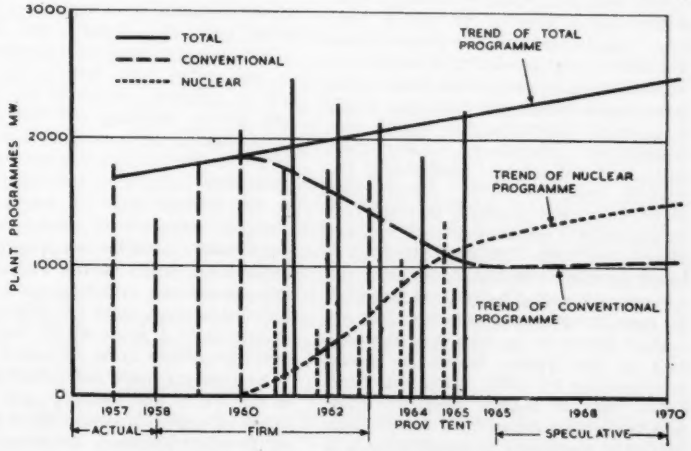


Fig. 2.—Annual programme for conventional and nuclear plant, showing possible trends.



* A credit figure of 0.35 d/kWh is roughly equivalent to a plutonium value of twice that currently quoted in the U.S. for uranium enriched to over 90%. Present U.S.A.E.C. price for highly enriched uranium is $17/g.

limit depends on raising the top temperature that can be achieved in the reactor. The vital problem lies in the development of the fuel elements. With magnesium canning recent designs have limited the can temperature to around 450°C and it is possible that this can be raised to the maximum which is around 475°C. An alternative canning material must, therefore, be chosen. Zirconium, although attractive in water-cooled reactors, is not applicable to carbon dioxide cooled systems because of the reaction with the gas at temperatures over 500°C.

Beryllium, on the other hand, with a melting point of 1,285°C is compatible with dry CO_2 up to temperatures of 600°C and is also compatible with uranium at this temperature. It is, however, expensive and toxic and we could not afford to make a straight substitution of beryllium for magnesium alloy in reactors of the type at present being built even though this permitted a maximum can temperature of 600°C. Increased power ratings over the present 2 or 3 MW/t up to 8 to 10 MW/t must be achieved. Fuel element shape therefore must change in order to reduce the temperature gradient within the fuel to an acceptable level and the present rods replaced by plates or clusters of pins of diameter say 0.3 in. The second arrangement would reduce the temperature difference between the centre of the fuel element and the can surface to 54°C and might allow the use of metallic uranium—although if gas outlet temperature is to be in the range 550°C to 600°C the centre uranium temperature would be dangerously high. The change of shape, whilst increasing heat transfer decreases reactivity and enrichment is therefore necessary. Economics then force a longer burn-up in the fuel and it is doubtful if this can be attained with metallic uranium and ceramic forms must be developed. This again reduces reactivity somewhat and very high burn-up figures of the order of 10,000 MWd/t are required.

If the research necessary, in order to bring down the capital cost of nuclear power plants, is not complete and sufficiently well established by 1966/67 when orders would have to be placed, then either uneconomic nuclear power plants will have to be installed or alternatively, we shall have to swing back towards the use of conventional power plants. Fig. 2 is a graph illustrating the annual programmes of conventional nuclear plant up to 1965 with a broad indication of the possible trend to 1970. Total plant requirements will gradually increase year by year with a preponderance of nuclear plant after 1964. Present planning is based on three considerations: using the optimum amount of home-produced coal, no new oil-burning installations and for nuclear power to be related to the base load on the system, which it should accommodate by 1970. After that time, unless costs of nuclear plant are competitive on a reducing load factor, then instead of continuing to install plant at a rate of not less than 1,400 MW per annum, the figure may fall to 300-400 MW to match the probable growth in the base load. The alternative is to install nuclear plants even though generation costs would be higher.

Having already started a swing away from the conventional side, absorbing scarce scientific and technical manpower, it would be unfortunate if there were to be a temporary reversal back to conventional plant. The prospective fuel supply position, however, made the present programme appear necessary and we must, therefore, show such skill in development, design and operation as to enable us to undertake a very difficult programme without failure. It is of outstanding importance that the limited resources for research and development should be directed unrelentingly to the solution of those problems which must be elucidated in the next 10 years. Only those resources which are surplus should be allocated to work on ideas which are unlikely to be of industrial interest within 15 or 20 years.

INDUSTRIAL VIEWPOINT

Overseas Prospects Reviewed by Sir Claude Gibb

(Abstract of paper "The Development of Nuclear Energy for Electricity Supply Overseas")

IT is not always realized that in burning coal or oil we are using up capital, in that the coal or oil are irreplaceable and without a world cataclysm could not be recreated. Britain has already faced the serious effect of greatly reduced coal exports and has not, as yet, found an alternative export with which to produce regularly a favourable balance of trade. World coal and oil reserves are great, but are not inexhaustible and the projected increases in world energy demands show clearly how necessary it is to develop, as quickly as possible, alternative ways of providing that additional energy which almost certainly must be in the form of electricity. Electricity produced by the fusion of some of the lighter atoms is a possibility at some unknown time in the future. It is an exciting and promising possibility and may well be developed in time to meet the long-term needs of the world, but it is to the fission of the heavy atoms that we must look for assistance in the immediate and short-term future.

Britain's need for a supplementary fuel is so great that research and development on a very large and adequate scale is proceeding both within the A.E.A. and in industry. Much of the research and testing necessary for that development requires equipment on a scale and of a cost that is quite beyond the ability of private industry to provide for itself at the present stage of world nuclear demand. Industry is already spending huge sums annually on research and engineering design studies and will find this expenditure crippling unless orders for nuclear equipment are received on a scale and at a price which will enable that expenditure to be recovered.

Assessments made independently within the A.E.A. and industry have given a figure of approximately 1,000 man years as the effort necessary to reach the prototype design stage of a new reactor. This figure corresponded to the effort required to prepare the tender for one of the first 300 MW nuclear stations in Britain and the preparation of a tender for a subsequent single 200 MW station exceeded 500 man years.

Extremely detailed information regarding the design and construction of Calder Hall has been given to the world and much information on the Consortia's stations published. Hence the main thing British industry has to sell in highly industrialized countries is experience in design details, in construction and in operating experience additional to that already obtained from Calder Hall. It is just that detailed experience which can and almost certainly would enable savings of many millions of pounds to be made on each nuclear station built. It is therefore experience and specialized components which British industry can and does offer to European and other highly industrialized countries.

High interest rates and low load factor call for minimum possible capital costs with fuel costs of lesser importance. Hence, if by the use of enriched and therefore expensive fuel a nuclear station of lower capital cost per kilowatt can be constructed such a station may be more economic than a natural uranium-fuelled one. For strategic reasons, there are strong arguments in favour of developing these reactors which can employ natural uranium, but for small and medium units (i.e., up to 20 MW and between 20 MW and 100 MW) natural uranium reactors, except in special cases, appear to be uneconomic.

If it were possible to have firm prices quoted for enriched fuels and their availability to be assured without any form of reservation, then the reactor designer's problems would be greatly simplified.

The Exponential Experiment at Imperial College

By J. M. KAY, M.A., Ph.D. and R. E. STRICKLAND, M.A.

The necessity for a sub-critical assembly as an aid to reactor design is shown, and an account given of design and construction work at Imperial College of Science and Technology, by the nuclear power group of the Mechanical Engineering Department.

THE engineering design of a nuclear reactor must start with a detailed calculation of the physics of the reactor core. In an ideal world, it might be possible to carry out this basic design calculation entirely by theoretical methods, using only the fundamental nuclear data on cross-sections, etc., appropriate to the core materials. In practice, however, as in the case of most other types of engineering plant, exact analytical treatment is not possible. The extreme complexity of the system necessitates an over-simplified theory of neutron reactions and neutron diffusion. Our calculations can at the best be only approximate, and it is necessary to appeal to direct measurement, either on previously completed reactors, or on specially constructed experimental assemblies, to provide the practical working values of the physical constants to be used in the design calculations.

In the case of a heterogeneous nuclear reactor core the calculations fall into two main divisions. First of all, one pictures a unit cell of the proposed lattice functioning as part of an infinite system and estimates are made for the values of the four factors η, ϵ, p, and f, which, when multiplied together, give the infinite reproduction constant k_∞. Subsequently, the reactor core is regarded as an effectively homogeneous system, and the estimate of critical size of the core is made with the help of a simplified theory of neutron slowing-down and diffusion, taken in conjunction with the appropriate boundary conditions. For a complete reactor core, using the simplest "one-group" theory, we have a diffusion equation, expressed in terms of neutron flux ϕ, of the form:—

$$\nabla^2\phi + \kappa^2\phi = 0$$

$$\text{where } \kappa^2 = \frac{(k_\infty - 1)}{M^2}$$

κ^2 is known as the *Laplacian*, or in American terminology as the "buckling" for the system.

M^2 is the *migration area* for the reactor core.

One of the most important estimates to be made, therefore, is that of the correct numerical value of the Laplacian κ^2 or the migration area M^2 for the composite reactor core. In practice, owing to the non-isotropic nature of a heterogeneous reactor, different values must be assigned to M^2 on the one hand for diffusion axially in the direction of the fuel channels, and on the other hand for diffusion in a direction at right angles to the fuel rods, or radially in the case of a cylindrical reactor core.

If it is possible to construct a zero-energy critical assembly, then the physics design may be verified directly and appropriate values determined for M_z^2 and M_r^2. This is the normal procedure for reactor systems using enriched fuel where the core dimensions are reasonably small. It is not generally feasible, however, in the case of a large reactor, especially of the natural uranium graphite-moderated type, since the size and cost of a critical assembly would be excessive. For this reason, experimental measurements are normally made in the first instance, on a *sub-critical assembly* using, perhaps, only about one-tenth of the quantity of uranium and moderator required for criticality. One or more neutron sources must be provided, and these may conveniently be of the radium-beryllium, polonium-beryllium, or antimony-beryllium type.

With a sub-critical assembly, the neutron flux will normally fall away in an exponential manner with the distance measured from the neutron source or source-plane, hence the description *exponential experiment*. One of the requirements with an experimental assembly of this type, therefore, is to measure the neutron flux at different points throughout the stack. Another type of measurement, which can be carried out with a suitably designed sub-critical assembly, is concerned with the local variation of the neutron flux distribution in the neighbourhood of a fuel element. This is of particular relevance in determining the values of the thermal utilization factor f and the resonance escape probability p. It is also of importance in connection with the design of control rods and with the use of absorbing material in the core of a reactor. Measurements of the local flux distribution are described as *fine-structure experiments*.

The Sub-critical Assembly at Imperial College

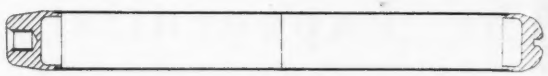
The design of a natural uranium-graphite assembly for use in connection with the post-graduate course in nuclear power was started at Imperial College during the summer of 1957. Owing to the severe space restrictions imposed on the nuclear power group during the reconstruction work at Imperial College, it was only possible to secure improvised laboratory accommodation.

Possession of a small laboratory at basement level in the Goldsmiths' building was obtained on September 23, 1957. Removal of old equipment, the construction of a new concrete foundation block, the installation of a hand-operated overhead crane, and minor structural alterations were completed by the end of January, 1958. In the meantime, the detailed designs for all the components of the assembly had been prepared and essential materials had been ordered. Stacking of the machined graphite blocks was started on March 3, and the main assembly was completed by March 20. The first set of irradiated antimony sources was delivered on May 13, 1958, and loading of uranium commenced on the following day.

Construction

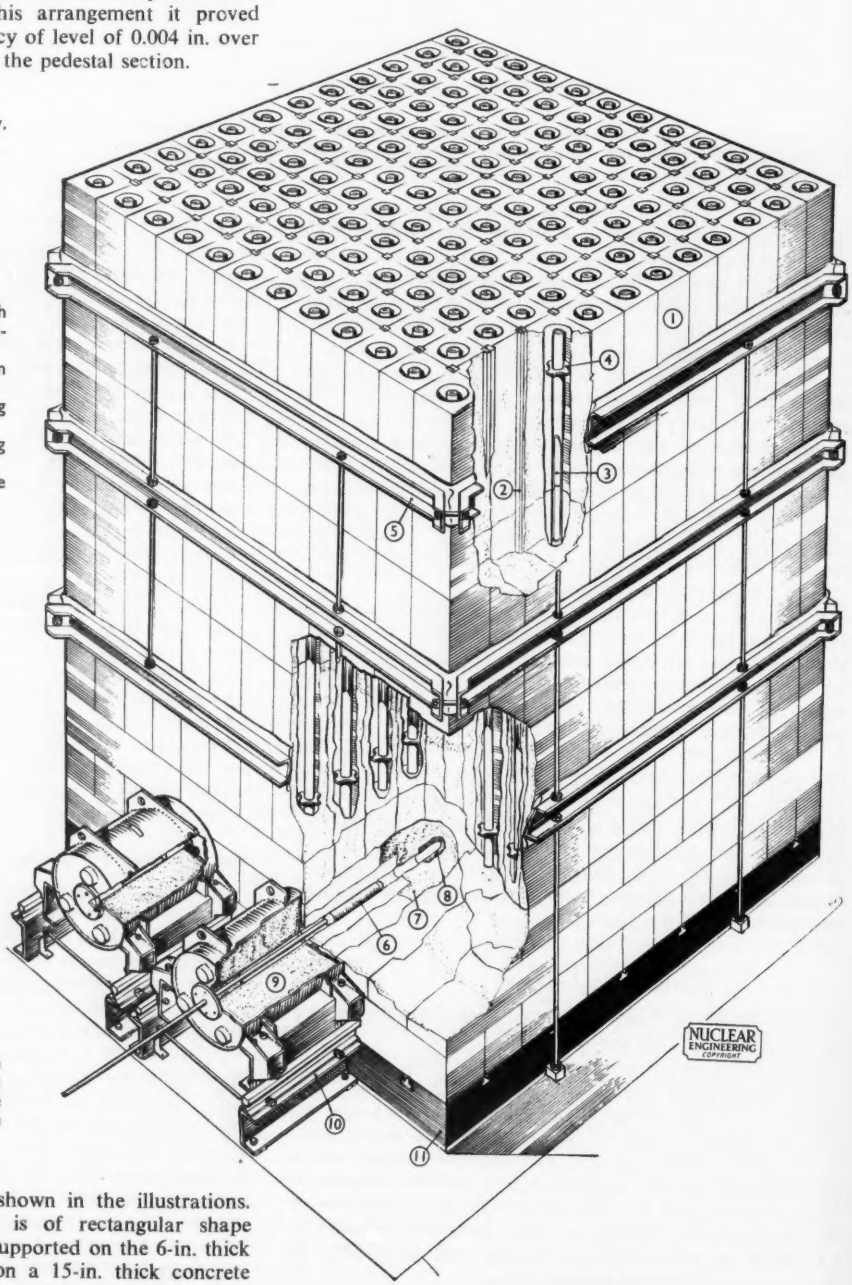
One of the most difficult problems in constructing a graphite assembly is in providing a flat surface of adequate

strength and rigidity on which to build up the graphite structure. It is not usually possible, without special techniques and a higher standard of workmanship than is normally obtainable, to achieve a sufficient degree of flatness with a plain concrete base. Careful consideration was given to other alternatives, but the conclusion was reached that a heavily ribbed cast-iron machined bedplate would be the best answer. With this arrangement it proved possible to maintain an accuracy of level of 0.004 in. over the surface of the first layer of the pedestal section.



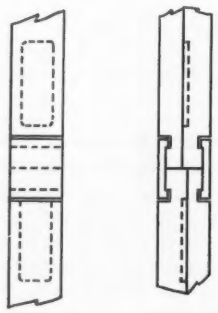
Detail of antimony source (6 in main drawing). Stainless steel capsule with 21g. walls; overall length 9¾ in.

Cut-away drawing of the assembly.



KEY

1. Graphite block
2. Graphite keying bar with accommodation for measurement foils (see detail)
3. Uranium fuel rods in aluminium tube
4. Aluminium spider for locating fuel element
5. Aluminium channels for bracing structure.
6. Antimony source on long handle (see detail)
7. Lead block
8. Beryllium sleeve
9. Lead-filled coffin
10. Support rails for coffin
11. Cast iron base plate



Detail of joint for split graphite keying bars, showing accommodation for measuring foils. The bars are 1¼ in. square and 29 in. long; the length of the joint is 1⅛ in.

The general arrangement is shown in the illustrations. The graphite assembly, which is of rectangular shape 8 ft × 8 ft × 9 ft 3 in. high, is supported on the 6-in. thick bedplate which, in turn, rests on a 15-in. thick concrete slab whose surface is protected by a ½-in. steel plate. The lower 2 ft of the graphite assembly forms a permanent pedestal, and its function is in the slowing-down and diffusion of the relatively fast neutrons from the antimony-beryllium sources. The main part of the graphite structure above the pedestal resembles that in an actual reactor core and is so arranged that it can be stacked either with the channels vertical as shown, or horizontal. This arrangement enables diffusion measurements to be made either in the axial or transverse directions, without greatly altering the position of the neutron sources.

Graphite Details

The general form of the graphite structure will be clear from the illustrations. The raw material was purchased in

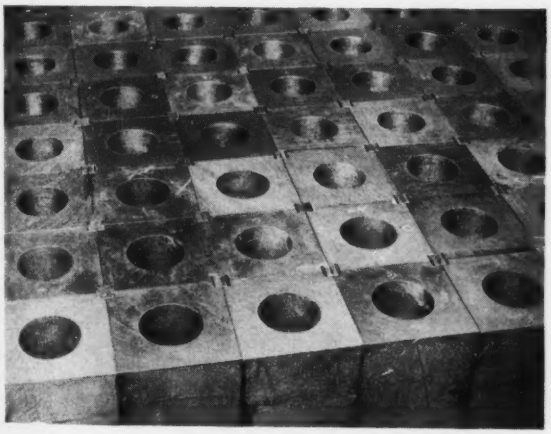
the form of graphite extrusions, obtained through the Industrial Group of the U.K.A.E.A., and the machining was carried out by Powell Duffryn Carbon Products Ltd.

The overall dimensions of the main blocks are 8 in. × 8 in. × 29 in., with a fuel channel of 4¼ in. diameter. The corners are cut away on the edges parallel to the axis, so as to form 1½-in. square-section measuring channels when the blocks are assembled. These channels are normally filled with square-section graphite bars, some of which are split to enable indium foils to be inserted for neutron flux measurements. The bars are connected together by channel-shaped graphite links. Graphite sleeves of 3⅜-in. internal diameter have also been machined as liners for the fuel channels to enable experiments to be made at a later date with a smaller size of channel diameter. It would also be possible to space out the lattice to a larger pitch than 8 in., should this be required, by using flat graphite tiles as spacing pieces between the main blocks. Altogether there are at present some 3,000 graphite lattice components of 16 distinct types in the main part of the stack, and 150 components of eight separate types in the pedestal.

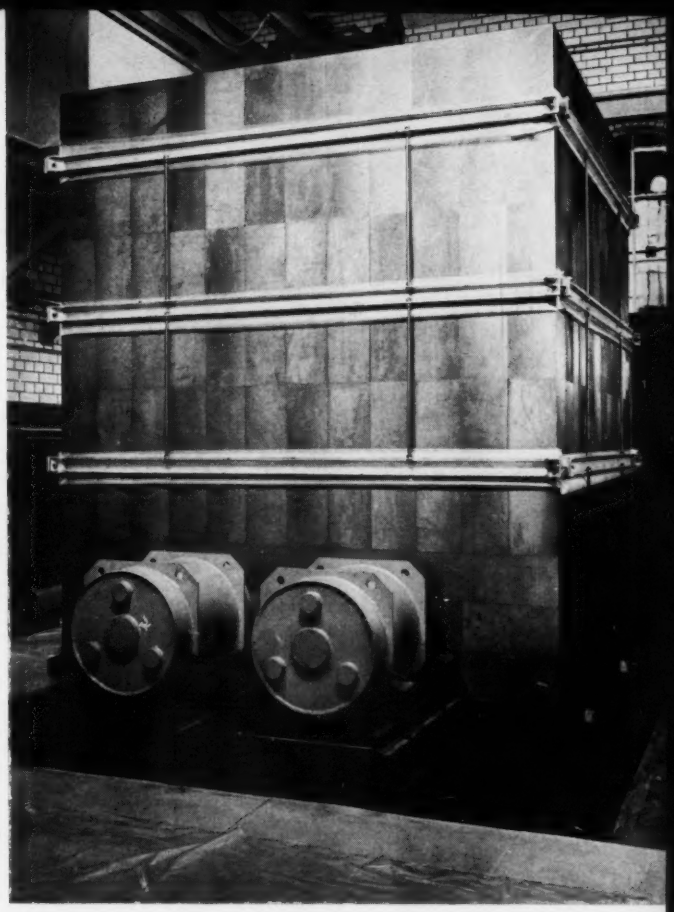
Great care was taken during the machining of the graphite to ensure clean conditions and avoidance of any contamination by material of high-absorption cross-sections. Check measurements were made of graphite cross-sections during and after machining. A similar degree of care was necessary to maintain clean conditions during the stacking operations in the laboratory.

Neutron Sources

Four antimony-beryllium sources are used and the general arrangement can be seen from the illustrations. The beryllium component is in the form of a sintered metallic sleeve, permanently located inside a high-purity lead shielding block built into the graphite pedestal structure. The antimony component is in the form of a metal slug of approximately 1 in. diameter and 8 in. length contained in a stainless-steel sheath. The antimony sources are normally irradiated in a reactor to a level of activity (for the Sb^{124} isotope) of approximately 25 curies. When not in use, the antimony sources are withdrawn by a long handling rod into lead-filled coffins, which provide adequate gamma radiation shielding. These coffins are also used for transport of the sources.



Close-up view of top of pile showing keying of graphite blocks.



General view of the assembly in the laboratory. The overhead crane bridge carrying the 3 ton hand and 5 cwt. power hoists can be seen in the left hand top corner.

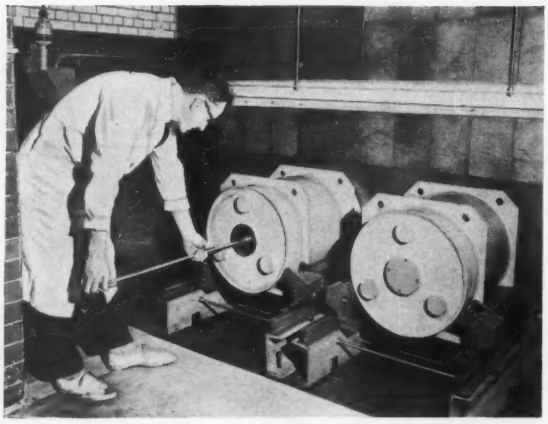
The coffins were designed by Imperial College and manufactured by Industrial Handling Equipment, Ltd. Fabricated from steel plate, they provide a 9½ in. radial thickness of lead around the source, and each measures 2 ft 3 in. by 1 ft 8 in. dia. with an overall weight of 35 cwt.

Fuel Element Support

The cut-away view shows the arrangement of the fuel elements. Each element is a 1-in. diameter natural uranium rod, 11½ in. long, aluminium-canned. Eight elements are contained in a long, thin-walled aluminium tube of super-pure quality, and each tube is located in the centre of a graphite channel by means of three thin aluminium spiders situated near the top, centre, and bottom of the channel. A full charge of fuel comprises 144 tubes; that is, 1,152 fuel elements. The simple geometry of this arrangement, together with the use of only one pure structural material of low neutron absorption, goes far towards eliminating local distortion of the neutron flux.

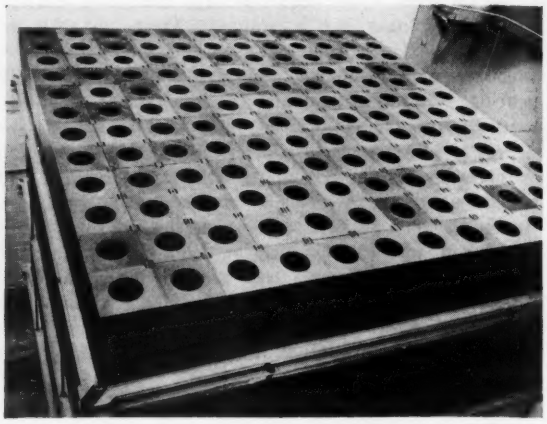
Handling Arrangements

Handling problems are complicated slightly by the siting of the laboratory at basement level. A 3-ton, hand-operated travelling crane was installed to handle the cast iron bedplate and the four coffins. A 5-cwt, friction-controlled hoist was temporarily erected to handle the delivery of some 36 tons of packed machined graphite components. Finally, a 5-cwt, electrically-operated hoist was installed to minimize the manhandling of the graphite blocks. The crab of this hoist runs the length of the 3-ton crane bridge, and can cover the whole area of the room.



(Left) View of one end showing method of handling source into and out of the coffin.

(Below) General view of the graphite pile from above during assembly.



In order to lift one of the lattice blocks, a machine chuck is tightened in the bore to a known extent by means of a torque wrench. The block can then be safely lifted by an eye-bolt screwed into the chuck. In this way, the entire lattice structure, together with the graphite measuring bars, was assembled by two men (apart from those unpacking and cleaning) in five days.

Measuring Techniques

A direct reading of the thermal neutron flux is obtained with a BF_3 proportional counter. This instrument has a sensitivity of 0.3 counts per unit of thermal neutron flux. A less direct but more flexible method of measurement is one using indium foils. Two indium leaves, each measuring 0.005 in. × ¾ in. × 1 in., are cemented with aluminium to form a foil 0.025 in. thick. Provision is made for siting the foil both in the measuring channels and in the fuel channels. The active indium isotope emits β-particles with a half-life of 54 minutes. The β-activity is counted in double-sided lead castles containing two Geiger-counters situated on either side of the foil. A battery of six castles is controlled by a master timing-unit, each castle having its own quench unit and scaler.

Besides the measurements of radiation inside the stack, regular external monitoring is carried out to keep a safety check on the gamma- and neutron-radiation levels.

(The Imperial College exponential experiment is the first University-owned and operated sub-critical assembly in the U.K. Other Universities are considering the installation of equivalent systems, but only Queen Mary College can be said to have plans crystallized—a light water moderated natural uranium assembly is scheduled for operation at Q.M. in the autumn. Construction was completed three months ago but agreement has not yet been reached with the A.E.A. on the purchase terms for the special uranium elements. A.E.I. is continuing to make its sub-critical assembly at Aldermaston available to the Universities.—Ed.)

Die unterhalb kritischer Grösse bleibende Reaktoreinrichtung im Imperial College

Berechnungen für einen Reaktor Entwurf können immer nur Annäherungswerte ergeben, und die Verwendung einer den kritischen Punkt erreichenden Null-Energie Einrichtung zur Bestätigung der Richtigkeit der Berechnungen ist ausserordentlich teuer. Dies trifft insbesondere bei einem mit natürlichem Uran arbeitenden Reaktor zu. Eine ganz beträchtliche Menge von Werten kann man aber schon einer experimentellen Einrichtung, die unter der kritischen Grösse bleibt, oder einem exponentiellen Versuch entnehmen. Solch eine Einrichtung ist kürzlich am Imperial College in London fertig geworden, und der Aufsatz beschreibt den Entwurf und den Aufbau. Der gesamte Graphitblock bedeckt eine Fläche von 2,4×2,4 m², die Gesamthöhe ist 2,8 m. Die einzelnen Graphitblöcke sind 20,32 cm im Quadrat und 73,7 cm lang und sie haben Ausschnitte an den Kanten für quadratische Graphitkeile, die innere Ausnehmungen haben, in die Messfolien eingelegt werden können. Als Neutronenquellen dienen solche des Antimon-Beryllium Typs, die in bleigefüllten Behältern gehalten und an langen Stangen in den Reaktor eingesetzt werden.

L'Ajustage Sub-Critique à l'"Imperial College"

Les calculs de conception d'un réacteur ne peuvent être qu'approximatifs et l'emploi d'un ajustage critique à énergie zéro pour les confirmer est excessivement coûteux; ceci en particulier dans le cas d'un réacteur d'uranium naturel. On peut obtenir un nombre considérable de renseignements d'un ajustage sub-critique ou expérience exponentielle. Un tel dispositif a récemment été mis au point à l'" Imperial College " de Londres, et cet article en décrit le projet et la construction. La cheminée en graphite a une superficie d'approximativement 2.4×2.4 mètres, la hauteur totale étant de 2.8 mètres. Les blocs de graphite sont de 20.32 cms×20.32 cms et 73.7 cms en longeur et ont des arêtes coupées afin de prendre des clefs carrés de graphite, qui ont des enfonçures intérieures pour l'insertion des lames de mesure. Les sources de neutron sont du type " antimoine-beryllium ", contenues dans des " cerceuils " remplis de plomb et insérées à l'intérieur du réacteur à l'aide de longues tiges.

El Conjunto Sub-Crítico en el " Imperial College "

Los cálculos de diseño de reactor sólo pueden per aproximados y el uso de un conjunto crítico de " energía-cero " para su confirmación es costosísimo, particularmente en el caso de un reactor de uranio natural. Se puede obtener una cantidad considerable de información de un conjunto sub-crítico o experimento exponencial. Reciente se ha completado un dispositivo de esta naturaleza en el " Imperial College " de Londres, y el artículo describe su diseño y construcción. La chimenea de grafito tiene un área de 2,4×2,4 metros aproximadamente, siendo su altura total de 2,8 metros. Los bloques de grafito son de 20,32 cm.×20,32 cm. y de 73,7 cm. de largo y tienen bordes recortados para tomar llaves cuadradas de grafito, las que tienen rebajos internos para la inserción de hojas metálicas de medición. Las fuentes de neutrones son del tipo de antimonio-berilio, contenidas en " atahudes " llenados de plomo e insertados dentro del reactor con varillas largas.

Pressure Regulation in Glove Box Working

A Simple and Practical Proportional Control Valve

By J. M. NORTH, B.Sc.
(Metallurgy Division A.E.R.E., Harwell)

IN glove boxes handling toxic materials it is conventional practice to maintain the gas pressure at about 1 in. water gauge below atmospheric pressure.[1] This pressure difference ensures that in the event of small leaks in the glove box structure, or in damaged gloves or posting bags, the spread of toxic materials into the laboratory is minimized.

The ease of work in gloves in a glove box is a function of the differential pressure. With a pressure difference less than ½ in. w.g., gloves fit closely to the hand and forearm and become "clammy" after a time; at differentials greater than 1½ in. w.g. gloves swell from the hands and sensitivity of feel is lost. Thus the ideal differential is between −½ and −1½ in. w.g.

Many processes carried out in glove boxes require either an inert atmosphere for metallurgical use or a flow of air through the box for chemical applications. In the case of a high purity inert atmosphere a flow of gas through the box is necessary to maintain the purity. This is due to the ingress of air, either through leaks or in air admitted to the box during posting-in by the bag sealing technique. There is also diffusion of water vapour through the rubber gloves and p.v.c. bags.[2]

In the α-active handling laboratory at A.E.R.E. the argon for the boxes is supplied either from bottles or from a recirculating purification plant.[3] The adjustment of box pressure is by valves in the inlet and extract lines, the supply and extract mains being controlled at set pressures. There is thus no definite control point at which the box pressure is maintained, but the box balances out at some point between the delivery and extract pressures. When the box pressure is disturbed, e.g., by introducing the hands into the gloves, or by posting through a bag, the pressure takes some time to return to balance.

The device to be described gives a definite control of box pressure relative to laboratory pressure. It gives proportional control of both inlet and extract flows so that the further the box pressure is from its set value the greater is the restoring force. This is of particular help with boxes of small volume.

As entirely mechanical operation was required the only force available to operate the valves was the pressure differential of 1 in. w.g. (~0.05 p.s.i.) between glove box and atmosphere. No suitable metal bellows for this differential were available, so a spring-loaded p.v.c. tube was used instead. From glove box experience with similar p.v.c. a life of at least a year was anticipated.

A schematic drawing of the regulator is shown in Fig. 1. The 0.007 in. thick p.v.c. tube (A), 8 in. dia. by 6 in. long, is sealed between end plate (B) and moving plate (C). Attached and sealed to the centre of plate (C) is a ¼-in.-dia. ground stainless-steel rod (D) which slides in seals (E) and (F) in the centres of end plate (B) and the opposite end plate (G). The end plates are held by tie rods (H).

Argon is delivered to the glove box at 20 in. w.g. (~1 p.s.i.) and the extract is

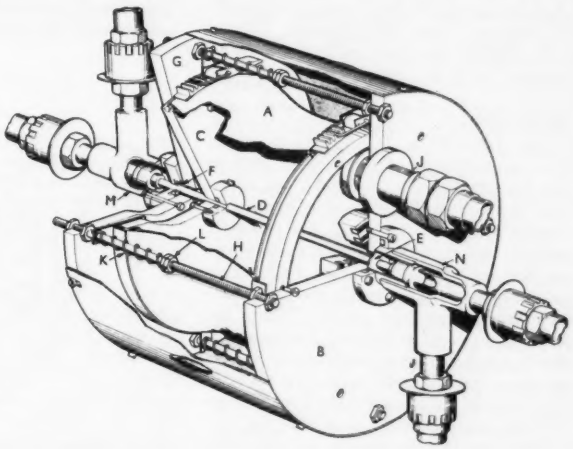


Fig. 1.—General arrangement of regulator.

−12 in. w.g. Connecting pipes are ½ in. bore, so a force of about 0.2 lb is necessary to hold the argon supply valve shut. With 0.05 p.s.i. over the 8-in.-dia. tube a force of about 2 lb is available, to which must be added a component due to the radial collapsing of the tube. The total is ample to close either valve and overcome the friction of the sliding seals.

The sliding seals (E) and (F) are not the same. Inlet seal (F) must be gas tight to prevent argon loss, and a rubber oil seal with metal inset ("Gaco") was used. Extract seal (E) does not require to be gas tight, and a plain brass bush $\frac{1}{16}$ in. thick with about 0.002 in. clearance on dia. was used.

The pressure connection (J) should be of wide bore and short to reduce the time lag between pressure variations in the box and actuation of the regulator. With small boxes (e.g. 10 cu. ft) a 1-in. bore tube 12 in. long is satisfactory; for larger boxes, with greater inertia, a longer tube is permissible.

The compression springs (K) tensioning the p.v.c. tube fit over the tie rods between projections from the free end of the tube, and locknuts (L). Adjustment of spring tension by the locknuts sets the pressure at which the glove box is controlled.

As the glove box pressure varies, the p.v.c. tube follows and the centre rod slides to and fro. On the ends of this rod are bosses surfaced on the ends with flat rubber discs, which open and close two simple valves (M) and (N). Valve M is connected in the argon inlet supply to the box, and valve N in the extract. If the glove box begins to pressurize, the p.v.c. tube is extended by the springs, valve M starts to close, reducing the inlet flow, while at the same time valve N opens wider giving greater extract flow. The system thus returns towards equilibrium.

Proportional control is obtained by arranging that when one valve is closed the radial gap on the opposite valve is equal to the cross-sectional area of the pipe, when any small movement of the centre shaft will result in a change of gas flow through the valves.

Operational Behaviour

Several regulators have been fitted to glove boxes for periods up to seven months, and have required no maintenance in this time. With a pressure transmitting tube of the size recommended, the regulators maintain the box pressure within the range −½ to −1½ in. w.g. for all inlet flows up to 1½ cu. ft/min and for all extract "suck" from zero to maximum −12 in. w.g.

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2. Catherall, A., "Gloves for use in dry boxes." *A.E.R.E. Report* GBS7(1957).
3. Ashburn, A. G., and Harris, W. E. "Purification plant designed to provide high purity argon for special glove box work." *A.E.R.E. Report* GBS16(1957).

Refs. 2 and 3 are included in "The Proceedings of the Glove Box Symposium held at A.E.R.E., Harwell, 1957," to be published by Butterworths Publications, Ltd.

A Commercial Irradiation Service

New MV Laboratory Formally Opened

WHAT is believed to be Britain's first commercial irradiation facility was inaugurated on May 29, when the new laboratory at the Metropolitan-Vickers Barton Works was formally opened by Mr. H. West, Director of Electrical Engineering.

There are, in the U.K., several irradiation laboratories already in operation and some of them do, from time to time, carry out work for other companies but they do not offer a short-term hire service. In contrast with the situation in the U.S., industry has been relatively slow to demand such a service.

Applications

The possibilities of irradiation which have already been demonstrated include the preservation of foodstuffs, the disinfestation and sterilization of substances as widely separated as grain and surgical sutures, and mutation of plants and seeds. In the rubber and plastics field, it is possible not only to modify the properties of existing materials, such as raising the melting point of polythene, for example, but to synthesize new materials, or known materials by different processes, through the effects of polymerization, cross-linking, chain scission, and grafting.

The irradiation source of the new laboratory is, of course, a linear accelerator, in which Metropolitan-Vickers has specialized for some years, the first linear accelerator in the world to be used for X-ray therapy being installed in 1950, at Hammersmith.

Irradiation is frequently carried out using β- or γ-emitting isotopes or fission products, and it may be of interest to compare the alternative methods. Although the results of irradiation do not alter with the source, there are essential differences, not only in the ability to switch off a machine, but in the amount of energy available. A beam current of 100μA from a 4 MeV machine can produce results comparable with a 4 MeV β-source of one million curies.

In addition there are essential differences in the energy absorption characteristics. The accelerator produces a substantially monochromatic beam of high-speed electrons. These are slowed down on passing through an absorber, the rate of energy decrease, in a material of uniform density, being nearly constant (at least at high energies), until the beam energy is less than the ionization energy of the material, i.e. until they are stopped. As the beam is monoenergetic, the particles have a fixed and equal range, and the thickness of the irradiation sample (or the energy of the beam) can be controlled so that this range is the same as the thickness. A reasonably uniform dose is thus given to the subject. Furthermore, the particles emerge from the machine as a true beam and distance from sample is not critical.

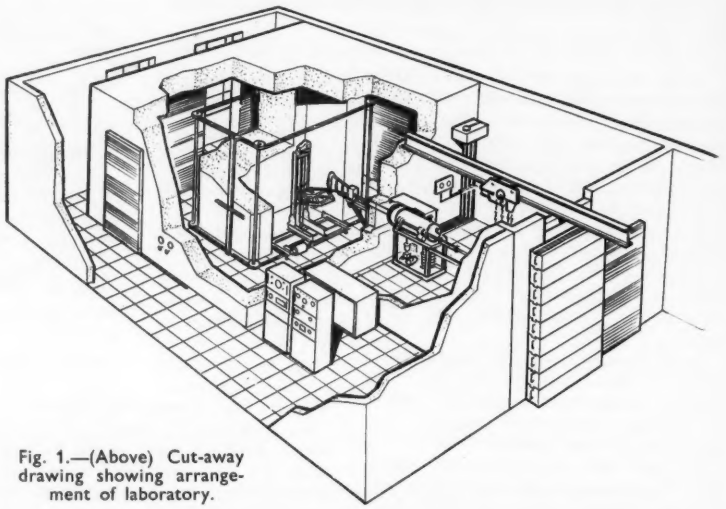


Fig. 1.—(Above) Cut-away drawing showing arrangement of laboratory.

With both β- and γ-sources the R^2 distance rule applies and, although a collimated beam can be produced, focusing is not possible. Unless, therefore, a 4π irradiation geometry can be achieved, a great deal of the source energy is lost. A radioactive β-source emits, not monoenergetic β-rays, but particles with energies ranging from zero to the maximum value (i.e., the value used to denote the radiation). The peak in the energy spectrum occurs at something like one-third peak energy and the spectrum shape is such that the energy released in

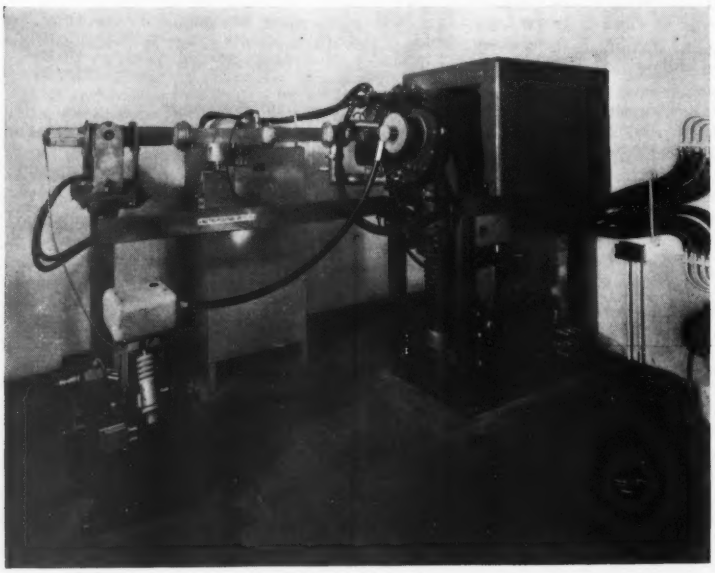
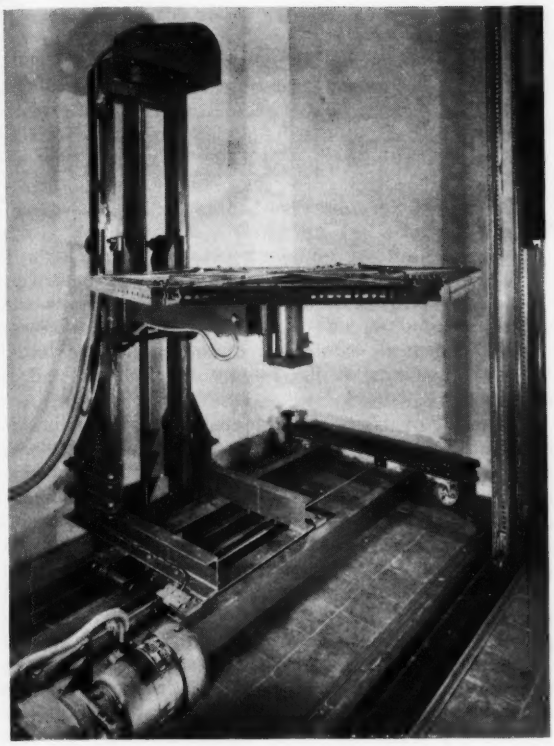


Fig 2.—(Left) The accelerator room.



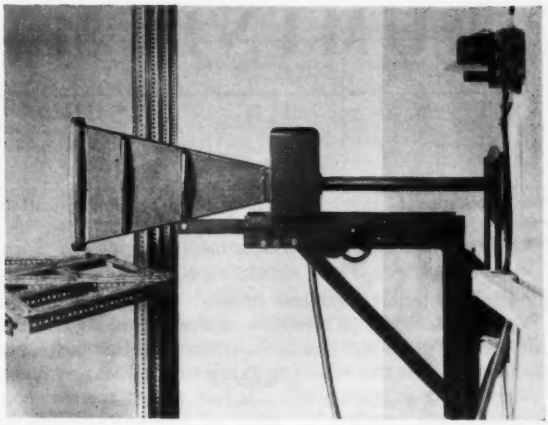


Fig. 3.—(Above) The scanner head showing arrangement for racking in and out.

Fig. 4.—(Left) The rotating specimen tables. Some of the Dexion slats of the conveyor system can be seen on the right.

the subject decreases exponentially with distance from the surface. Only with thin samples can a uniform dose be given.

Gamma rays, although emitted as a "line" spectrum, have a similar exponential distance/energy relationship, and uniform irradiation implies "wastage" of the transmitted beam in the same way. In round figures, the range in organic material of unit specific gravity of a

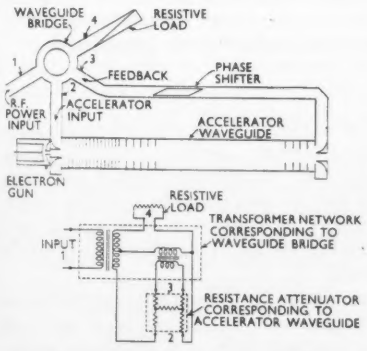


Fig. 5.—Schematic diagram of r.f. feedback with the low-frequency equivalent circuit.

4 MeV electron is 2 cm, the half-thickness of 4 MeV β-rays would be about 0.35 cm whereas the half-thickness for 4 MeV γ-rays is in the region of 23 cm.

The MV Accelerator

The methods of accelerating electrons by means of a radio-frequency field in a loaded (i.e., corrugated) waveguide are generally known, but one modification in the MV machine is of interest, in that the r.f. power feedback first suggested by R. B. R. S. Harvie and L. B. Mullett (*Proc. Phys. Soc.*, B **62**, 270). R.F. power from the output end of the accelerator is returned and combined with the incoming power via a bridge circuit giving an increased power flux in the accelerator. A schematic diagram is shown in Fig. 5, together with its low-frequency analogue, or equivalent circuit.

The general arrangement of the laboratory is shown in Fig. 1. The accelerator itself, together with its associated magnetron, vacuum pumps, etc. (Fig. 2), is located in a room separate from the actual irradiation room, and the high-energy electron beam is conveyed through the dividing wall by means of a telescopic tube which terminates in a sector-shaped scanner head (Fig. 3), having an output window of aluminium foil. The area scanned by the beam is about 12 in. by $\frac{3}{4}$ in., and the scanning frequency 10 cycles/sec. The mean beam current is 125 microamp.

The arrangements for presenting material to the beam are designed so as to suit any size or type of specimens. A rotating table with motor-driven raising and traversing motions is provided. There is also a variable-speed conveyor consisting of upper and lower horizontal driving chains, carrying vertical slats of "Dexion" which was selected as offering the maximum facility for securing practically any type of object. An interesting feature of this conveyor is that it passes right round an exceptionally heavy shielding block so that, if required, it could be safely loaded and unloaded from the other side for continuous operation.

The conveyor and table, together with all other controls, timing gear, etc., are located outside the shielded enclosure. Interlocks are fitted to all doors.

Irradiation Costs

The laboratory can be hired for £50 for an 8-hour day, and the approximate costs of treating a few typical materials are shown in Table 1. It will, of course, be realized that the highest utilization factor is achieved for bulk material irradiated from both sides, the maximum thickness for organic material then approaching 2 in. The figures assume that the conveyor system and beam scanning arrangements give the most efficient use of the machine. With a higher-powered machine, capacity would be raised and costs lowered in view of reduced capital cost per kW output.

TABLE 1.
TYPICAL IRRADIATION COSTS
(Based on a Hire Charge of £50 per 8-hour day)

Process	Typical Dose	Estimated Utilization	Capacity of 600-W machine	Approx. cost
		%		
Prevention of sprouting (potatoes) ..	10,000 rad	50	11 tons/h	11s. 9d. ton
Disinfestation of grain	50,000 rad	80	3.36 tons/h	37s. ton
Preservation of foodstuffs	50,000 rad	45	4,320 lb/h	¼d. lb
	0.5 megarad	45	432 lb/h	4½d. lb
Sterilization of drugs, etc.	2 megarad	80 (in bulk)	192 lb/h	7½d. lb
		5 (in phials)	12.0 lb/h	10s. lb
Curing of rubbers	5 megarad	80 (in bulk)	77 lb/h	1s. 8d. lb
		20 (mouldings)	24 lb/h	5s. 3d. lb
Treatment of plastics	25 megarad	80 (in bulk)	16 lb/h	8s. lb
		25 (mouldings)	5 lb/h	25s. lb

ALUMINIUM—

and Its Alloys

By J. M. BOLD, M.Eng., A.I.M.
(U.K.A.E.A. I. G., Culcheth Laboratories)

The application of aluminium and its alloys as canning materials for nuclear power reactors is considered, and the relevant physical, chemical and mechanical properties are discussed.

OF all materials with low thermal neutron absorption, aluminium was an inevitable choice as canning material for the early thermal reactors. It had the best-developed technology, was the easiest to fabricate, and was available commercially in high purity. It had a high thermal conductivity, was resistant to oxidation and to corrosion by pure water below 100°C, was easily worked by conventional methods, and could be welded and brazed readily.

Aluminium has been used all over the world for low-temperature reactors, air- and water-cooled, both for research and for plutonium production. In the U.K. it has been used for the cans in BEPO and GLEEP at Harwell, for the cans of the plutonium-producing piles at Windscale and for the fuel element assemblies of DIDO at Harwell and DMTR at Dounreay. It has been superseded by magnesium alloy for the power reactors at Calder and Chapel Cross and for those being constructed by the consortia, for reasons of neutron economy, the greater ductility at high temperatures of the magnesium alloy and its compatibility with uranium which eliminates the necessity of using interlayers.

The can has been designed as a ductile container which protects the fuel from attack by the coolant and which will accommodate swelling of the fuel without fracture. Thus, ductility of the canning material at the operating temperature has been of prime importance while the actual creep strength has been a secondary consideration, subject only to the requirement that the heat-transfer fins should retain their shape under the stress caused by the coolant flow.

Occurrence

Aluminium is widely distributed round the world and occurs to the extent of 7.3% of the earth's crust—mainly as silicates in the form of silicate rocks, clays and slates. Weathering and disintegration of silicate rocks has resulted in extensive deposits of bauxite, a hydrated oxide ($Al_2O_3H_2O$; $Al_2O_3.3H_2O$) and this and cryolite (Na_3AlF_6) are the two minerals used in the production of aluminium. The principal supplies of bauxite, which contains 50/65% alumina, come from the United States, Surinam, British Guiana, France, Hungary, Italy, Jugoslavia, Russia and Dutch East Indies; the largest deposits of cryolite occur in Greenland.

Extraction

Aluminium is extracted by electrolytic reduction of aluminium oxide and any impurities such as oxides of iron, silicon and titanium are reduced at the same time.

Bauxite is purified by the Bayer process in which it is digested under pressure with caustic soda solution; the alumina is extracted as a solution of sodium aluminate and is separated from the "red mud" of impurities by settling and filtration. Hydrated alumina is separated from the aluminate by seeding and precipitation and is converted to the oxide Al_2O_3 by calcination.

The purified oxide is dissolved in molten cryolite and electrolized at about 1,000°C on a continuous basis in large carbon-lined steel cells using carbon anodes. Molten aluminium collects at the bottom of the cells and is periodically withdrawn.[1]

The purity of this primary aluminium depends upon the care and skill with which the raw materials have been selected and prepared and with which the reduction process[1] has been carried out. With the utmost care a purity of 99.9% can be achieved with 0.05% silicon, 0.05% iron and traces of other impurities but, in general, the product is between 99.5% and 99.9% pure.

Higher purities are obtained by an electrolytic three-layer process in which the top layer (cathode) is molten pure aluminium, the middle layer (electrolyte) is a molten salt mixture and the bottom layer (anode) is impure aluminium, densified by alloying with copper. In the original Hoopes process, the electrolyte was a mixture of cryolite and aluminium and barium fluorides and the process was operated at 900°/1,000°C; 99.9% pure aluminium was produced. Later processes operate at a lower temperature. The Gadeau process uses an electrolyte of cryolite, aluminium fluoride, sodium chloride and barium chloride at 740°/750°C; the S.A.I.A. process operates at 740°C with an electrolyte of sodium fluoride, aluminium fluoride (in excess of the cryolite proportion) and two alkaline earth fluorides, e.g. barium and calcium fluoride. Both processes make a 99.99% pure[2] product.

The production of one pound of primary aluminium requires about 10 kWh of electricity, so that its economic production is confined to areas where cheap electric power is available; usually from hydro-electric installations.

Principal Products

Numerous alloys of aluminium are manufactured commercially, the most common alloying elements being copper, silicon, manganese, magnesium, nickel and zinc. They are most often used in combination; with the exception of the binary alloys of aluminium with silicon and with magnesium, commercial alloys of aluminium with a single element are rare.

Aluminium and its alloys are commonly available as castings, forgings, forged bar, sheet, extruded bar and sections and drawn rod and wire. A relatively recent introduction, sintered aluminium powder (S.A.P.) is available as extrusions, stampings, sheet and tube. It is made by extrusion from a hot-pressed, sintered compact of aluminium powder and is subsequently worked to the final form; the powder particles are produced with an oxide film of controlled thickness.

Physical Properties

Aluminium, with a density of 2.70 g/cc, is one of the lightest metals; of the fabricated metals, only magnesium and beryllium have a lower density. Density is affected

by alloying and the alloys vary in density between 2.55 and 2.89 g/cc.

The thermal conductivity of the pure metal is high, but is reduced slightly by the presence of impurities. Alloying results in a significant loss of conductivity and, in the heat-treatable alloys, precipitation hardening causes a further reduction to a value which may be little more than half that of the pure metal.

The coefficient of thermal expansion is high, increasing with temperature, and is about one and a half times that of uranium; it is reduced slightly by the presence of impurities and by alloying. In fuel elements, differential expansions during temperature fluctuations may lead to relative movement between can and rod, and must be distributed as uniformly as possible to avoid undue stress on the can ends; such movement can be localized by pressing the can, after sealing, into circumferential " anti-ratcheting " grooves on the rod.

Aluminium is one of the metals most transparent to thermal neutrons and has an absorption cross-section of 130 millibarns. Of the fabricated metals, only beryllium, magnesium and zirconium have lower cross-sections (Table 5). Most of the conventional alloys of aluminium contain alloying elements with much greater absorption of thermal neutrons, and Table 6 shows the effect on thermal cross-section of adding 0.5% and 1% of specific elements to aluminium; it is clear that material containing substantial amounts of manganese, copper, or nickel would have a marked effect on neutron economy. Thermal cross-sections have been calculated for some typical commercial wrought alloys and are shown in Table 7. With the exception of the aluminium-magnesium-chromium alloy, the values are all significantly greater than that of aluminium.

Cold Working of Alloys

Like other metals, aluminium and its alloys strain-harden during cold working. For the range of working customary in commercial operation, the increase in tensile strength is directly proportional to the amount of cold work, expressed as a fractional reduction of cross-sectional area. For higher reductions, the proportional increase in tensile strength increases sharply.

The 0.2% proof stress rises rapidly with the application of cold work, but the proportional increase falls with increasing work, until, after about 20% reduction, the rate of increase in proof stress is similar to that in tensile strength.

Ductility, as determined by elongation, decreases rapidly with the application of small amounts of cold work; subsequent application of similar increments of work has a decreasing effect as the aggregate reduction in cross-section area increases. Half, or even more, of the initial elongation may be lost by a reduction of 20%; after a reduction of 60% is attained, further reductions cause relatively little change in elongation values.

Annealing restores to cold-worked material the initial values of tensile strength, proof stress and elongation. The effect of cold work is illustrated by the values in Table A obtained on annealed 99% pure aluminium sheet.

Strain hardening by cold work occurs also in heat-treated alloys, due to flattening after heat treatment or to deliberately cold working heat treated material to obtain higher strengths than are obtainable by heat treatment alone.

Heat Treatment

In the ingots of aluminium alloys the alloying elements are present for the most part in the form of eutectic or of relatively large particles of rich alloy and these are broken up and distributed by subsequent hot working.

TABLE A
Effect of Cold Working on 99% Pure Aluminium Sheet

Reduction %	0.2% proof stress ton/in.²	Ultimate stress ton/in.²	Elongation %	Hardness B.H.N.
—	2.2	5.4	25	23
20	5.8	6.7	12	28
40	6.3	7.6	9	32
60	7.6	9.0	6	38
80	9.4	10.8	5	44

A number of alloying elements, e.g. copper, magnesium, silicon and manganese have a considerably higher solid solubility in aluminium at elevated temperatures than at room temperature. When alloys containing these elements are heated at a temperature not quite high enough to melt the eutectic constituents, the elements go into solution; if the metal is then cooled rapidly, for example by quenching, the excess alloying elements do not separate out immediately. In this state, " solution treated," the material is soft and ductile. The alloying elements gradually precipitate in accordance with their true solubilities at room temperature as very fine particles too small to be resolved by the optical microscope. This " natural ageing " results in an increase in hardness, tensile strength and proof stress and a decrease in ductility. Precipitation can be accelerated by heating at a slightly elevated temperature—" artificial ageing "—and, in some alloys, greater increases in strength and hardness can be obtained by this means than by ageing at room temperature. Artificial ageing temperatures are usually in the range of 120°/210°C.

TABLE B
Effect of Cold Working on 1/16 in. Sheet of Al—4.5 Cu—1.5 Mg—0.6 Mn Alloy

	0.2% proof stress ton/in.²	Ultimate stress ton/in.²	Elongation %
Annealed	4.9	12.0	22
Solution treated and naturally aged	19.4	29.7	21
Solution treated, naturally aged and flattened	20.4	30.2	19
Solution treated, naturally aged and cold rolled	25.3	32.3	13

Prolonged heating or use of too high a temperature—" over-ageing "—can lead to aggregation of the submicroscopic particles to a size at which they are easily seen under the microscope; this aggregation results in a loss of strength and hardness. Precipitation after quenching can be suppressed by holding the material at sub-zero temperatures. Use of too high a solution treatment temperature results in melting of the eutectic constituents, which segregate on the grain boundaries and embrittle the material (overheating).

Mechanical Properties

The tensile properties of super-pure and 99.5% aluminium are shown in Table 4. The presence of impurities raises the strength and reduces ductility in the annealed state, and increases the strength in the fully cold-worked state, without significantly affecting the ductility.

In Table 7, the properties of 99.0% aluminium and a number of typical wrought alloys[1, 3, 4] are shown. The strength at room temperature varies from 5.4 tons/in² for 99% aluminium to nearly 40 tons/in² with respective elongations of 45% and 10%.

At elevated temperatures, however, the strength of both work-hardened and heat-treated alloys falls off rapidly, with a corresponding increase in ductility. At temperatures in the working range of power reactors, even the nickel-

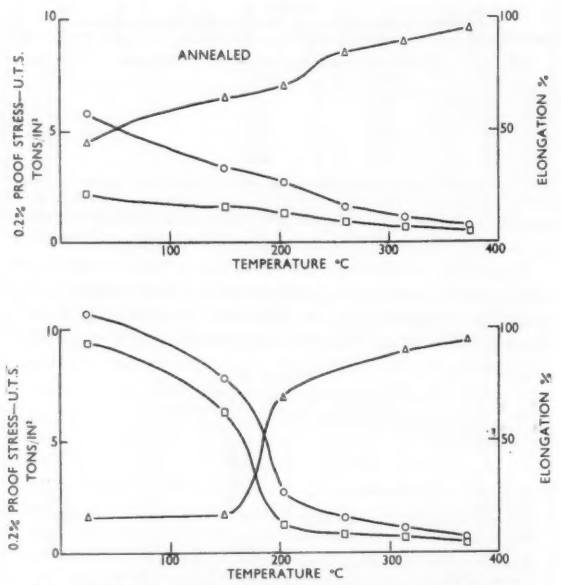


Fig. 1.—Effect of long soaking at temperature on the tensile properties of annealed and half hard 99% Al.

bearing alloys, specially developed for work at elevated temperatures, are only a little better than 99% aluminium (Table 7 and Figs. 1-10). Thus at 370°C, the highest strength after prolonged soaking at temperature is of the order of 3 tons/in² as against 0.7 tons/in² for 99% aluminium. This slight gain in hot strength does not compensate for the increase in absorption cross-section, by alloying, of up to 40% and, from the viewpoint of neutron economy, these alloys are unattractive.

Considerably higher hot strength is shown by S.A.P., which has a strength at 400°C of 9 tons/in²; however, in this material, initial ductility is low compared with aluminium, and decreases with rise of temperature. For a

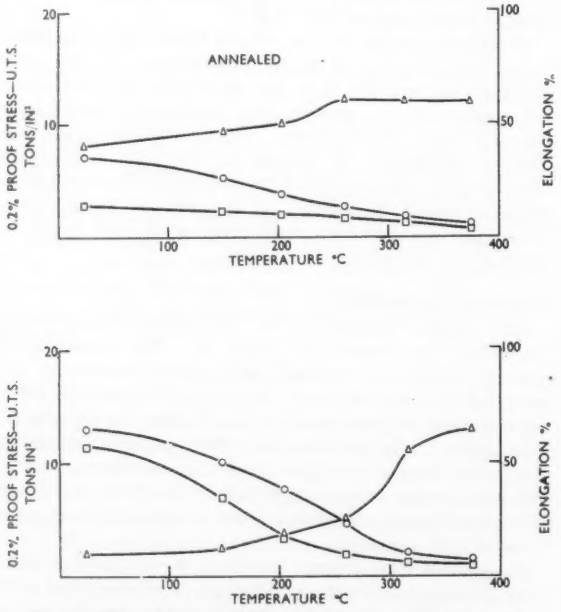


Fig. 2.—Effect of long soaking at temperature on the tensile properties of annealed and half hard Al—1.2 Mn alloy.

ductile container intended to accommodate swelling of the fuel, this material is unsuitable.

Creep tests by McKeown[5] on 99.8% aluminium show that, at 20°C, 50°C and 80°C, creep persists at a measurable rate ($<0.5\times10^{-7}$ in/in, h) after 5,000 hours at stresses of 3,000, 1,600 and 600 lb/in² respectively. At 250°C and 450°C, coarse-grained material (1.4 mm dia.) was much more resistant to creep than medium-grained material (0.09 mm dia.). At 250°C, coarse-grained material showed no measurable continuous creep at stresses up to 1,000 lb/in²,

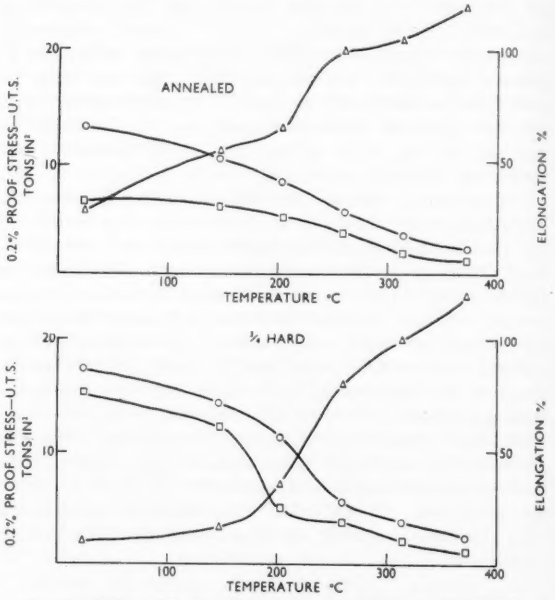


Fig. 3.—Effect of long soaking at temperature on the tensile properties of annealed and ¾-hard Al—2.5 Mg—0.25 Cr alloy.

while in medium-grained material creep persisted after 3,000 hours at 250 lb/in². At 450°C, medium-grained material showed creep continuing under a stress of 25 lb/in² after 3,000 hours while, in the coarse-grained material, creep virtually ceased at a stress of 50 lb/in² after 500 hours. Two medium-grained specimens failed at similar general strain rates, one at 250°C and the other at 450°C. At 250°C, the fracture was transgranular with a general elongation of 45%; at 450°C, it was intergranular and the general elongation was only 26%. One coarse-grained specimen failed at 450° C, intergranularly, with no general elongation. For test results see Tables 8 and 9.

The reduction in ductility at elevated temperatures under creep conditions has been investigated by Servi and Grant[6] in creep tests at constant stress on 99.995% aluminium, 99.3% aluminium and aluminium-1.2% manganese alloy at temperatures up to 1,100°F (590°C). They report a change from "low temperature" to "high temperature" deformation which is associated with the beginning of grain boundary flow and a change from a ductile to a brittle form of fracture. The transition depends on the purity of the aluminium, stress, strain rate and temperature; it is more marked in impure aluminium and in the aluminium-manganese alloy than in the pure metal. Transition occurs at the point of change in the slope of the straight lines obtained by plotting the log. of the applied stress against the log. of either the minimum creep rate or of the time to rupture (Figs. 11-14).

For a given temperature, impurities lower the transition strain rate or raise the transition stress. At temperatures

close to the melting point, transition stress and strain rate have definite values; below a certain critical temperature, no transition will be observed in a reasonable testing time. The stress and strain rate at which transition occurs can be related to the temperature in accordance with Mott's theory of grain boundary slip although the presence of impurities necessitates an alteration of the constants in Mott's equation.

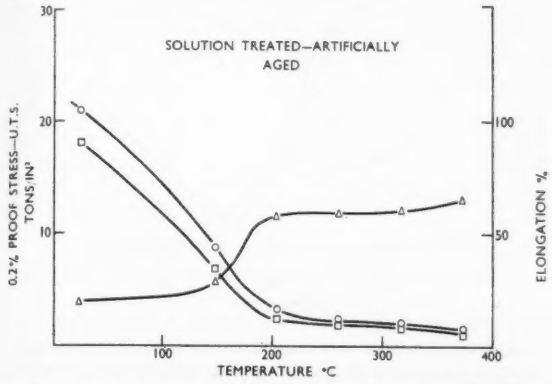


Fig. 4.—Effect of long soaking at temperature on the tensile properties of solution-treated and aged Al—1.0 Si—0.6 Mg —0.25 Cr alloy.

Results of creep and creep rupture tests on 99.0% aluminium by Simmons and Cross[7] are given in Table 10 and in Figs. 15 and 16. Deformation at fracture ranged from 23% to 71% at 400°C and from 30% to 57% at 450°C.

During comparative tests on 99.7% aluminium and magnesium alloy Magnox C, local elongations were measured on the fractured specimens at intervals of ¼%. These are shown in Fig. 16 for fracture times of approximately 1,000 hours at 350°C.[8] The superior ductility of the magnesium alloy is clear and on this basis the material would be preferable to aluminium as a canning material.

Compatibility

Aluminium is incompatible with uranium at temperatures above 200°C due to the formation of the intermetallic compound UAl_3.[9] This compound has a higher specific volume than its component metals and its progressive formation at local points of contact with an aluminium can may result in rupture of the can.

With thorium, aluminium forms a similar system to that with uranium[10] and similar incompatibility is to be expected. With plutonium a number of intermetallic compounds are formed.[11]

The reactions of aluminium with metals, other than fuels, which give a solidus less than 600°C are shown in Table 9. The solidus is higher than 600°C with gold, boron, barium, beryllium, cobalt, chromium, iron, manganese, molybdenum, nickel, platinum, antimony, titanium and zirconium. Only with zinc, magnesium and germanium are alloys formed which have an appreciable aluminium content and are liquid[9] below 500°C. Aluminium has no reaction with graphite at reactor temperatures.

Up to 500°C aluminium shows excellent resistance to attack[9] by carbon dioxide. With hydrogen there is normally no reaction. A hydride AlH can be produced by an electric discharge between aluminium electrodes in hydrogen under reduced pressure and evaporated films of aluminium have been shown[12] to absorb hydrogen subjected to an ionizing discharge.

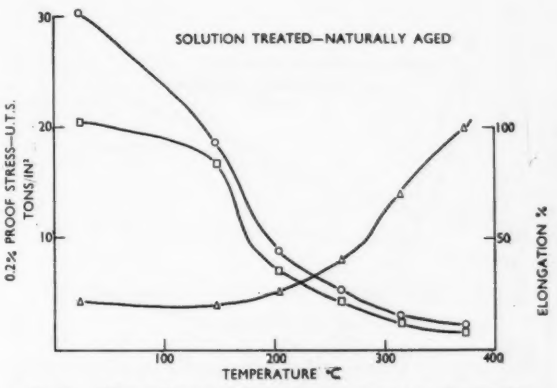


Fig. 5.—Effect of long soaking at temperature on the tensile properties of solution-treated and aged Al—4.5 Cu—1.5 Mg—0.6 Mn alloy

Diffusion of hydrogen through aluminium is negligible below 400°C and, above this temperature, measured rates of diffusion show wide variation, probably due to differences in the texture and state of oxidation of the surfaces. Diffusion has been increased by mechanical planing of the surface in the test atmosphere during the experiment. Diffusion rates of 2.6×10^{-3} c.c. (STP) cm²/mm,h and 4.2×10^{-4} c.c. (STP) cm²/mm,h have been measured at 580°C, for clean and oxide-coated aluminium, using a hydrogen pressure[13, 14] of 760 mm. At 20 atmospheres pressure, diffusion of hydrogen has been found to be negligible at temperatures below 450°C, but at this temperature diffusion occurs without surface treatment.[15] Rates of diffusion at 500°C of 4×10^{-7} and 7×10^{-6} c.c. (STP) cm²/mm,h decreasing with time have been determined. The variation and the progressive reduction in rate may have been due to oxide film formation by impurities[16] in the hydrogen.

Corrosion

Aluminium is a very active metal and comes high in the electrochemical series. This activity results in a very thin tough film of inert oxide on the surface of aluminium and its alloys, which re-forms immediately on metal surfaces freshly exposed by machining, pickling, damage, etc. In aluminium alloys the quality and continuity of the film are impaired by the presence of alloying metal and, for this reason, rolled plate and sheet of heat-treatable alloys are

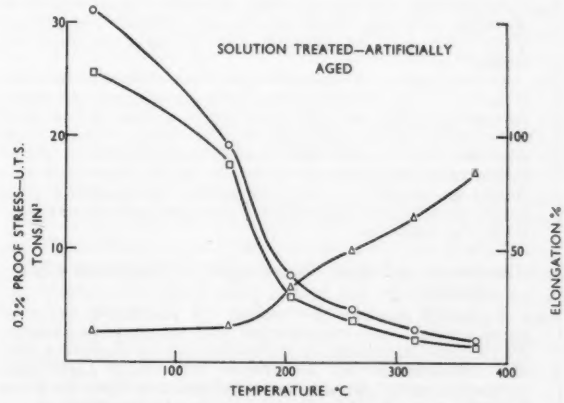


Fig. 6.—Effect of long soaking at temperature on the tensile properties of solution-treated and aged Al—4.4 Cu—0.8 Si—0.8 Mn—0.4 Mg alloy.

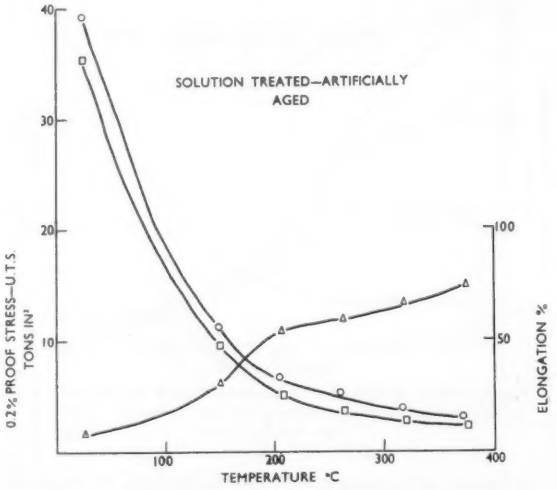
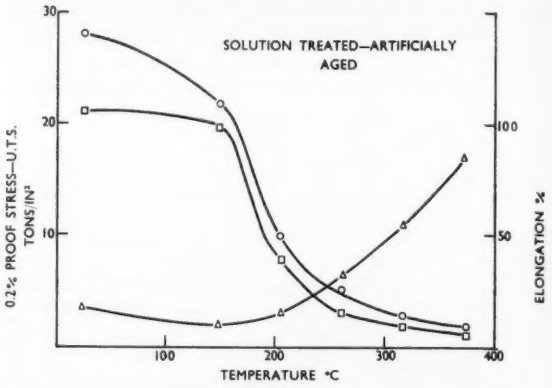


Fig. 7.—(Left) Effect of long soaking at temperature on the tensile properties of solution-treated and aged Al—5.5 Zn—2.5 Mg—1.5 Cu—0.2 Mn—0.25 Cr alloy.

Fig. 8.—(Below) Effect of long soaking at temperature on the tensile properties of solution-treated and aged Al—4.0 Cu—2.0 Ni—0.5 Mg alloy.



often integrally coated on both sides with pure aluminium. At ordinary temperatures, aluminium resists attack by atmospheric corrosion and by many chemicals including strong nitric acid, ammonia, sulphides and many organic compounds. It is attacked readily by caustic alkalis and by the halogen acids.

At temperatures below 100°C, aluminium is resistant to attack by pure water; the resistance to corrosion decreases with decreasing purity but even 99.0% aluminium is satisfactory at these temperatures.

At higher temperatures, such as would be encountered in power reactors using water as coolant or moderator, the rate of mode of attack change; high-purity aluminium, and to a lesser extent the impure metal, is susceptible to intergranular corrosion in high temperature pressurized water. At 300°C only a few hours are necessary for complete disintegration. At temperatures up to 200°C, intergranular corrosion of pure aluminium by distilled water is prevented by a sufficient degree of cold work but at higher temperatures attack is rapid.[17]

Attack on 99.0% aluminium is insignificant at, and below, 200°C, even when previously annealed at 400°C to simulate the effect of welding.[18] At these temperatures, initial attack is rapid but the corrosion rate levels off after a few hundred hours to about 0.001 in. per year. Above 200°C, attack is intergranular and blistering leads to rapidly increasing rates of attack.[19] Blistering is thought to be due to diffusion of corrosion-product hydrogen in monatomic form into the metal and to its re-formation as molecular hydrogen at subcutaneous voids or at imperfections in the lattice.[20]

The onset of blistering has been delayed, and the life of

L'Aluminium et ses Alliages comme Materiaux d'Emboitement

La production de l'aluminium est décrite brièvement et les propriétés physiques et mécaniques afférentes à son emploi comme matériau d'emboîtement sont exposées. Les propriétés des alliages commerciaux sont examinées brièvement. La compatibilité du métal avec les matériaux solides, liquides et gazeux que l'on rencontre dans le service de réacteur d'énergie fait l'objet d'une discussion quelque peu détaillée et les données de l'effet de l'irradiation sont exposées. Le remplacement de l'aluminium par l'alliage du magnésium comme matériau d'emboîtement pour les réacteurs d'énergie à gaz refroidi du Royaume Uni est signalé et l'emploi possible des alliages d'aluminium pour des réacteurs d'énergie ou d'eau lourde est indiqué.

La résistance à la corrosion par l'eau pressurisée à haute température des alliages d'aluminium nouvellement développés les rend adaptables aux réacteurs d'énergie utilisant de l'eau ou de l'eau lourde comme modérateur ou refroidisseur, et pour de tels réacteurs il est probable que le choix se fasse dans un proche avenir entre les alliages du zirconium ou de l'aluminium. En faisant un tel choix, le bas prix relatif, la disponibilité et la facilité de fabrication des alliages d'aluminium devront constituer un facteur important.

Aluminium und seine Legierungen als Brennstoff-Hülsenmaterial

Es werden kurz die Herstellung von Aluminium und seine physikalischen und mechanischen Eigenschaften beschrieben, die für seine Benutzung als Hülsenmaterial von Bedeutung sind. Die Eigenschaften der im Handel befindlichen Legierungen werden gestreift. Es wird dann ziemlich detailliert die Frage behandelt, wie das Metall sich mit den festen, flüssigen und gasförmigen Stoffen verträgt, die im Betrieb eines Atom-Kraftwerks angetroffen werden, und es werden dann Zahlen über die Wirkung der Bestrahlung gegeben. Das Fallenlassen von Aluminium zugunsten einer Magnesium-Legierung als Hülsenmaterial für gas-gekühlte Atom-Kraftwerke wird erwähnt und auf die Möglichkeit der Anwendung von Aluminium-Legierungen für Kraftwerke, die mit schwerem Wasser arbeiten, hingedeutet.

Die Korrosions-Festigkeit der neu-entwickelten Aluminium-Legierungen im Druckwasser bei hohen Temperaturen lässt sie für Kraftwerke zweckmässig erscheinen, die Wasser oder schweres Wasser als Moderator oder als Kühlmittel benutzen, und für solche Reaktoren liegt in der nächsten Zeit die Wahl wahrscheinlich zwischen den Legierungen des Zirkons und des Aluminiums. Die relative Billigkeit, leichte Beschaffbarkeit und einfache Fabrikation von Aluminium-Legierungen werden bei der Entscheidung ein wichtiger Faktor sein.

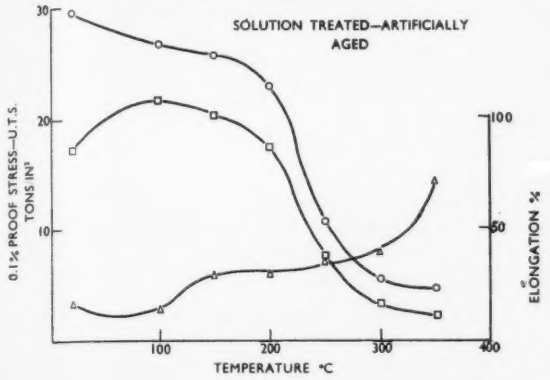
Aluminio y sus Aleaciones como Materiales de Envasar

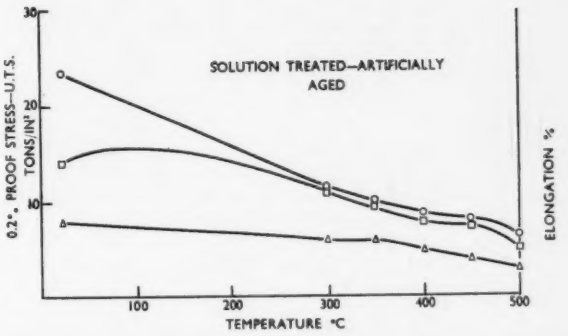
Se describe brevemente la producción de aluminio y se presentan las propiedades físicas y mecánicos pertinentes a su uso como un material de envasar. Se consideran brevemente las propiedades de las aleaciones comerciales. La compatibilidad del metal con materiales sólidos, líquidos y gaseosos que pueden ser encontrados en el servicio es discutida en algún detalle y se presentan datos sobre el efecto de irradiación. Se nota el reemplazo de aluminio por aleación de magnesio como material de envasar para los reactores de energía enfriados a gas del Reino Unido, y se indica el posible uso de aleaciones de aluminio para reactores de energía o agua pesada.

La resistencia a la corrosión por agua presurizada de elevada temperatura de las recientemente evolucionadas aleaciones de aluminio las hace adecuadas para los reactores los energía usando agua o agua pesada como moderador o enfriante, y para tales reactores en el futuro cercano la selección va a ser probablemente entre las aleaciones del zirconio o el aluminio. En hacer una selección semejante, la relativa baratura, disponibilidad y facilidad de fabricación de las aleaciones de aluminio tiene que ser un factor importante.

Fig. 9.—(Below) Effect of long soaking at temperature on the tensile properties of solution-treated and aged Al—2.2 Cu—1.4 Mg—1.0 Ni—1.2 Fe alloy.

Fig. 10.—(Right) Effect of long soaking at temperature on the tensile properties of S.A.P. bar.





99% aluminium in water at 315°C extended, by electrically coupling the aluminium to stainless steel or zirconium. It is prevented by adding, to the water, metal ions which are reduced on the aluminium to form deposits of low-hydrogen overvoltage metals; nickel, cobalt and cadmium are most effective but, unless the nickel solution is acidified to pH 3.5, basic nickel salts are formed as a slime.[20]

The temperature at which blistering and intergranular corrosion occur is raised by suitable alloying additions to the aluminium. Nickel, iron, titanium, copper, cobalt, molybdenum and tungsten have been found to restrain intergranular corrosion and of these nickel is most effective.[21]

Early results on experimental alloys have been encouraging. A corrosion rate of 0.0015 in. per year is reported for 99.0% aluminium enriched by 1% nickel.[20] On 2% Ni-2% Cu alloy at 300°C, still lower rates of attack are recorded in static water. In high-speed flowing water, corrosion occurs at leading edges and sharp corners, and the corrosion rate increases by an order of magnitude; erosion rounds off the corners and the local rate of attack decreases, indicating that by proper design this effect may be reduced considerably, if not eliminated.

Development is currently proceeding in the United Kingdom, Canada, and America on alloys of aluminium with nickel, iron and copper. Typical compositions are shown in Table 12 which also indicates their relative absorption of thermal neutrons compared to aluminium.

Fabrication

Forming.—Aluminium and its wrought alloys are ductile and are easily shaped at room temperature by the conventional methods of rolling, hammering, bending, pressing, rubber press forming, drop stamping, spinning and stretch forming.

The severity of deformation possible, e.g. the bend radius, will depend on the alloy and its state; thus, in bending, 20 S.W.G. aluminium sheet can be closed flat without cracking, while the same thickness sheet in hard-rolled aluminium or in fully heat-treated duralumin may require a radius of two or three times the sheet thickness for a successful 90° bend. Approximate working radii for a 90° bend in a number of alloys[1] are shown in Table 13.

Stretch forming requires smooth shapes, with relatively large radii. Where severe deformation is involved, it may be necessary to form in two or more stages with intermediate anneals. The final properties of the component will reflect the amount of deformation after the last heat treatment.

Heat-treatable alloys are usually formed in the solution-treated condition before precipitation has commenced; the material is formed in a ductile state without the prospect of distortion by a subsequent solution treatment. The blanks are solution-treated and either formed immediately or stored in a refrigerator until required.

Considerable improvement in the workability of aluminium alloys is obtainable by hot forming. In the strain-hardened materials, the working temperature must not be higher than 150°/200°C if significant softening is to be avoided; in heat-treated alloys, softening due to over-ageing may occur even at lower temperatures.

Joining.—The customary methods of joining—riveting, welding and brazing—are applicable to aluminium and its alloys. Resin bonding is a method developed in the aircraft industry for making high-strength joints.

In both welding and brazing, the heat applied has an annealing effect on the parent material adjacent to the joint, reducing the strength locally to that of the annealed material. In addition, in the heat-treated materials of higher strength, over-heating occurs in this region producing a brittle zone. Such materials are usually joined by riveting or by resistance-welding methods such as spot welding, seam welding and flash welding in which these effects are minimized by a short welding time and localized heat input or by pressure welding below the over-heating temperature.

Aluminium and aluminium-manganese, aluminium-magnesium and aluminium-magnesium-silicon alloys can be fusion welded satisfactorily by the oxy-acetylene, atomic hydrogen, metal-arc, carbon-arc and argon-arc processes using appropriate filler wire. They can also be spot-, seam- and flash-welded. For fusion welds in aluminium, aluminium is required as a filler and for aluminium-manganese alloy either self material or aluminium can be used. Aluminium-magnesium alloys require either aluminium-silicon alloy or high-magnesium aluminium-magnesium alloy. Aluminium-silicon is also used for the aluminium-magnesium-silicon alloys.

In all the fusion welding processes, other than argon-arc, a flux is necessary, applied separately or as a coating on the welding rod. All traces of the flux should be removed, after welding, by scrubbing in boiling water; if the joints are inaccessible, the flux should be neutralized by pickling in dilute sulphuric acid followed by thorough washing.

The process of cold pressure welding, in which thin aluminium and aluminium alloys are pressed together at room temperature by special tools which induce a high local deformation, has special application to circumferential sealing. It has been applied successfully in welding aluminium to other metals such as copper and brass.

Torch brazing of aluminium and its alloys uses aluminium-silicon brazing alloy—5% and 13% silicon—in conjunction with a flux.

In flux-bath brazing, the components are assembled in a jig with braze metal foil or wire between the surfaces to be joined, and the whole immersed in a bath of molten flux. The assembly is withdrawn and allowed to drain and finally the brazed assembly is pickled and washed to remove all trace of flux.

For use with this process, a special "brazing sheet" is available in which a cladding of brazing alloy has been applied to one or both sides of the sheet. The use of separate foils or wires of brazing alloy is avoided and the jigging of complicated assemblies for brazing is simplified.

S.A.P. can be joined by flash-welding but not by fusion-welding or brazing.[4]

In resin bonding, overlap joints in aluminium or aluminium alloy are assembled under heat and pressure using glues of thermo-plastic and thermo-setting resins. The temperatures used are not normally high enough to affect adversely the properties of the strain-hardened or precipitation-hardened materials used. In properly designed joints in sheet, shear strengths in excess of the tensile strength of the sheet have been developed. Such joints would be expected to be unsatisfactory in power reactors due both to the elevated temperature and to deterioration of the plastic bond material under irradiation.

Machining.—Aluminium and most of its commercial alloys have good machinability. It is possible to get good machining results on some alloys using the same tools as for steel, but, in general, tools used for aluminium and its alloys should have significantly greater top rake and side rake than those for steel. Recommended values are 30°/50° top rake, 10°/20° side rake and 8°/10° clearance. It is essential that the cutting edges be sharp and smooth and free from burrs and grinding wheel scratches. After grinding the tool should be hand stoned or lapped without altering significantly the angles or the contour of the cutting edge. Carbide-tipped tools are best, but high-speed steel, and even plain high-carbon steel can be used satisfactorily.

Wide ranges of cutting speeds and feeds can be used, but, in general, best results are obtained by using comparatively high speeds and fine to medium feeds; usually the highest speeds should be used with the finest feeds.

For best results, lubricant should be fed continuously to the tool. For general use, paraffin oil alone or mixed with lard oil is satisfactory. For heavy cuts and slow feeds, a heavier lubricant such as pure lard oil is needed. For milling, sawing and drilling, soluble oil is satisfactory.[1]

Effect of Reactor Conditions

During service in power reactors materials are exposed to elevated temperatures, to heavy bombardment by thermal and fast neutrons, to gamma irradiation of high intensity and, on the inside surface of the can, to the products of fission and their degradation products.

Steele and Wallace[22] investigated the effect of neutron bombardment on the room-temperature tensile properties of commercial aluminium, and of a number of commercial alloys. The specimens were water cooled to about 150°F (66°C) during irradiation by a total of 1.26×10^{21} neutrons/cm² with an estimated fast neutron exposure of 1×10^{20} neutrons/cm². Detailed results are shown in Table 14. Yield and tensile strengths were increased significantly by radiation in all cases, the increase being greatest in the annealed material; with annealed commercial aluminium and annealed Al-Mg-Si-Cr alloy, irradiation almost tripled the yield strength and doubled the tensile strength. The ductility of annealed material was reduced, but the reduction was considerably less than that expected from strain hardening to the same tensile strength. The ductility of alloys previously strain hardened or heat treated was either reduced slightly or actually increased by exposure.

Preliminary creep tests under irradiation are reported by Jones,[23] who used the resistance to air flow to measure the decrease in annular space between a tubular specimen under internal pressure and an outer cylindrical casing. At 50°C, with a hoop stress of approximately 3,500 lb/in.² generated by an internal pressure of 235 lb/in.², no significant change was made to a creep rate of approximately 2×10^{-5} in./in. day by exposure to a thermal flux of 6×10^{12} n/cm²,sec with an epithermal flux of 1.3×10^{12} n/cm²,sec.

Jeppson[24] bombarded 99% aluminium with 38 MeV alpha particles in a cyclotron at beam intensities up to 1.2×10^{13} particles/cm²,sec. Slight decreases in a creep rate of about 10^{-6}/sec were noted due to irradiation over the temperature range 160°/330°C but results were within the expected scatter range.

In the neutron-irradiation investigations the specimens were maintained at a relatively low temperature by water cooling. The elevated temperatures expected in power reactors are above the recrystallization temperature of aluminium and the hardening effects of irradiation are likely to be eliminated by continuous annealing.

Irradiation may affect the compatibility of aluminium with coolant or moderator. Experience with magnesium alloy cans at Calder gives no reason to expect increased reactivity of carbon dioxide due to reactor conditions. The effect, previously noted, of ionizing radiation on the absorption of hydrogen by aluminium suggests that the metal and its alloys may be unsuitable for use in a hydrogen-cooled reactor. Hittman and Kuhl[25] state that exposure to gamma radiation reduced the corrosion of duralumin-type alloy in water at room temperature. In-pile work is needed to assess the effect of reactor conditions on the corrosion of the new aluminium alloys resistant to high temperature, pressurized water.

The saturation activity of aluminium, due to the isotope of mass number 28 (half-life 2.3 min) is 13 millicuries for a neutron flux of 10^{11} neutrons/cm²,sec. As a canning material this will be insignificant compared with the activity of the fuel.

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Nuclear Engineering
DATA SHEET
No. 9. Aluminium

Symbol	Al
Atomic number	13
Atomic weight	26.98
Naturally occurring isotope	27 (100%)
Other isotopes	24 (2 sec)
	25 (6.5 sec)
	26 (10^6 y)
	28 (2.3 min)
	29 (6.6 min)
Crystal form	Face-centred cubic
Lattice constant	4.0408
Atomic diameter	2.856
Co-ordination number	12
Melting point	660.1°C
Boiling point	2,330°C
Latent heat of fusion	2.5 cal/mole
Latent heat of vaporization	69.6 cal/mole
Contraction on solidification	6.6%
Thermal neutron absorption cross-section	230 mbarn

TABLE 1
Physical Properties (2)

Purity	State	Density g/cc	Resistivity at 20°C μΩ/cm	Thermal conductivity at 100°C, c.g.s. units
Super pure	Sheet-annealed	2.70	2.68	0.57
	Sheet-hard			0.56
	Extruded			0.57
99.8%	Sheet-annealed	2.70	2.74	0.56
	Sheet-hard		2.76	0.55
	Extruded		2.79	0.55
99.5%	Sheet-annealed	2.71	2.80	0.55
	Sheet-hard		2.82	0.55
	Extruded		2.85	0.54
99.0%	Sheet-annealed	2.71	2.87	0.54
	Sheet-hard		2.89	0.54
	Extruded		2,86	0.54

TABLE 2
Thermal Properties (2)

Property		Super-pure	99%
Liquidus (°C)		660.2	657
Solidus (°C)			643
Specific heat at (cal/g,°C)	0°C	0.215*	0.222
	100°C	0.224	0.230
	200°C	0.235	0.237
	300°C	0.246	0.245
	400°C	0.257	0.253
Latent heat of fusion (cal/g)		94.6	93.0
Emissivity at 25°C		0.030	0.35/0.060
Coefficient of thermal expansion:			
	20°–100°C	23.86×10^{-6}	23.5×10^{-6}
	20°–200°C	24.58×10^{-6}	24.6×10^{-6}
	20°–300°C	25.45×10^{-6}	25.6×10^{-6}
	20°–400°C	26.49×10^{-6}	
	20°–500°C	27.68×10^{-6}	

* at 20°C.

TABLE 3
Properties of Molten Aluminium (2)

Purity	Property	Temperature	Value
Super-pure	Density (g/cc)	660°C	2.380
		700°C	2.369
		900°C	2.315
		1,100°C	2.261
Not stated	Electrical resistivity μΩ/cm	660°C	20.0
		700°C	20.4
		800°C	21.3
		900°C	22.2
Not stated	Thermal conductivity (c.g.s. units)	700°C	0.247
		790°C	0.290

Alloy	State	Calculated absorption compared to aluminium
99% aluminium	Annealed	1.02
	Hard	
Al–1.2 Mn	Annealed	1.34
	Hard	
Al–2.5 Mg–0.25 Cr	Annealed	1.01
	¾ hard	
Al–1.0 Si–0.6 Mg–0.25 Cr	Heat treated	1.04
Al–4.5 Cu–1.5 Mg–0.6 Mn	Annealed	1.44
	Heat treated	
Al–4.4 Cu–0.8 Si–0.8 Mn–0.4 Mg	Annealed	1.55
	Heat treated	
Al–5.5 Zn–2.5 Mg–1.5 Cu–0.2 Mn–0.25 Cr	Annealed	1.22
	Heat treated	
Al–4.0 Cu–2.0 Ni–0.5 Mg	Heat treated	1.42
Al–2.2 Cu–1.4 Mg–1.0 Ni–1.2 Fe	Heat treated	1.29
S.A.P. bar (13% oxides)		0.95
S.A.P. sheet (10% oxides)		0.96

* 0.1% proof stress. ‡ 400°C.

TABLE 3—Cont.
Properties of Molten Aluminium (2)

Purity	Property	Temperature	Value
Not stated	Specific heat (cal/g. °C)	660°/1,000°C	0.259
Super-pure	Viscosity (centipoises)	660°C	4.5
		700°C	2.9
		800°C	2.5
99.5%	Surface tension (dyne/cm)	660°C	915
		700°C	900
		800°C	865
Not stated	Boiling point (°C)		2,480
Not stated	Vapour pressure (mm Hg)	1,450°C	1
		1,790°C	10
		1,975°C	40
		2,110°C	100

TABLE 4
Tensile Properties of Aluminium Sheet (2)

Purity	State	0.2% Proof/stress tons/in.²	Ultimate stress tons/in.²	Elongation % on 10d
99.99%	Annealed	1.3	3.9	43
	Half-hard	2.9	4.9	19.7
	Hard	6.5	7.6	7.2
99.5%	Annealed	1.6	5.1	30
	Half-hard	3.2	6.4	12
	Hard	8.7	9.9	6.5

TABLE 5
Thermal Neutron Absorption Cross-sections of Aluminium and Some Other Metals

Metal	Absorption cross-section	
	Microscopic (barns/atom)	Macroscopic (cm^{-1})
Beryllium	0.010	0.00123
Magnesium	0.059	0.00254
Zirconium	0.180	0.00765
Aluminium	0.215	0.0130
Zinc	1.06	0.0697
Niobium	1.1	0.0599
Iron	2.43	0.2061
Chromium	2.9	0.2324
Copper	3.59	0.3025
Nickel	4.5	0.3792
Manganese	13.2	1.0420

TABLE 6
Effect of Common Alloying Elements on Thermal Neutron Absorption

Alloying element	Calculated absorption of thermal neutrons compared to aluminium	
	0.5% alloy	1% alloy
Beryllium	0.996	0.992
Chromium	1.032	1.065
Copper	1.029	1.058
Iron	1.022	1.045
Magnesium	0.997	0.993
Manganese	1.143	1.286
Nickel	1.044	1.088
Silicon	1.001	1.002
Titanium	1.078	1.155
Zinc	1.006	1.012

TABLE 7
Physical and Mechanical Properties of Typical Aluminium Alloys (1) (4)

State	Physical properties						Mechanical Properties at 20°C							Mechanic 370°C (lo	
	Calculated absorption compared to aluminium	Specific gravity at 20°C	Thermal conductivity at 20°C c.g.s. units	Co-efficient of thermal expansion ×10⁶ 20°/100°C	20°/200°C	20°/300°C	0.2% proof stress tons/in.²	Ultimate stress tons/in.²	Elongation %	Hardness B.H.N.	Endurance limit tons/in.²	Modulus of elasticity lb/in.²×10⁻⁶	Modulus of rigidity lb/in.²×10⁻⁶	0.2% proof stress tons/in.²	Ul s to
d	1.02	2.71	0.53	23.5	24.6	25.6	2.2	5.4	45	22	±2.2	10.0	3.85	0.5	
			0.52				9.4	10.7	25	44	±3.8			0.5	
d	1.34	2.73	0.46	23.2	24.2	25.1	2.7	7.1	40	28	±3.1	10.0	3.85	0.9	
			0.37				11.6	13.0	10	55	±4.5			0.9	
d	1.01	2.68	0.33	23.8	24.9	25.8	6.2	13.0	30	45	±7.6	10.2	3.85	1.1	
.. ..			0.33				15.2	17.4	10	74	±8.3			1.1	
ated ..	1.04	2.69	0.41	23.1	24.2	25.0	18.0	21.0	20	100	±4.9	10.2	3.85	1.3	
d	1.44	2.77	0.45	22.8	23.9	24.7	4.9	12.0	22	42	±5.3	10.6	3.85		
			0.29				20.5	30.4	22	120	±8.1			1.5	
ated ..															
d	1.55	2.80	0.46	22.5	23.6	24.5	6.3	12.0	18	45	±4.9	10.6	3.85		
			0.37				25.7	31.2	13	135	±8.1			1.5	
ated ..															
d	1.22	2.80		23.2	24.2	26.0	8.9	17.8	12			10.4	3.85		
			0.29				35.7	39.2	10	150	±10.0			2.2	
ated ..	1.42	2.80	0.46	22.4	23.3	24.2	21.0	28.0	17	130	±7.6	10.6	3.85	1.1	
ated ..	1.29	2.75	0.36	22.0	23.1	24.0	*20.9	30.8	13		±9.3	10.4	4.2	‡*1.7	
	0.95	2.80	0.40	19.5	20.5	21.3	14.1	23.6	8	104	±7.5	11.2	4.2	‡8.1	
	0.96	2.80	0.435	20.0	21.0	21.5	17.7	23.7	8		6.1	10.7		‡6.2	

2)

emperature	Value
60°/1,000°C	0.259
660°C	4.5
700°C	2.9
800°C	2.5
660°C	915
700°C	900
800°C	865
	2,480
1,450°C	1
1,790°C	10
1,975°C	40
2,110°C	100

et (2)

stress n.²	Elongation % on 10d
	43
	19.7
	7.2
	30
	12
	6.5

of Aluminium

section	
Macroscopic (cm⁻¹)	
	0.00123
	0.00254
	0.00765
	0.0130
	0.0697
	0.0599
	0.2061
	0.2324
	0.3025
	0.3792
	1.0420

rmal Neutron

hermal neutrons minium	
1% alloy	
	0.992
	1.065
	1.058
	1.045
	0.993
	1.286
	1.088
	1.002
	1.155
	1.012

TABLE 8
Creep Tests on Annealed 99.8% Aluminium Sheet (5)

Temp. °C	Stress lb/in.²	Extension % after 100 h	500 h	1,000 h	1,500 h	2,000 h	5,000 h	Final Creep in./in.
20	2,000	0.025	0.032	0.036	0.039	0.040	0.040	0
	2,500	0.082	0.090	0.092	0.092	0.092	0.092	0
	3,000	0.235	0.245	0.250	0.255	0.257	0.265	<0.5×10
	3,500	0.370	0.380	0.390	0.395	0.400	0.415	0.5×10
	4,000	0.940	1.145	1.280	1.365	1.435	1.700	4.5×10
50	1,600	0.045	0.052	0.057	0.064	0.070	0.080	<0.5×10
	1,900	0.052	0.075	0.085	0.090	0.095	0.110	0.5×10
	2,200	0.090	0.107	0.127	0.180	0.187	0.260	1.0×10
	2,500	0.213	0.280	0.324	0.345	0.355	0.415	2.0×10
80	600	0.020	0.023	0.025	0.030	0.032	0.038	<0.5×10
	800	0.022	0.027	0.035	0.040	0.043	0.055	0.5×10
	1,000	0.025	0.035	0.045	0.055	0.060	0.070	0.5×10
	1,200	0.030	0.047	0.065	0.070	0.082	0.110	1.0×10

* Discontinuities in creep curve.

TABLE 9
Creep Tests on Coarse and Medium Grained annealed 99.8% Aluminium Plate (5)

Grain size	Temp. °C	Stress lb/in.²	Extension % after 200 h	500 h	1,000 h	2,000 h	3,000 h	Durat h
Medium 0.09 mm dia.	250	200	0.02	0.02	0.025	0.03	0.04	3,20
		400	0.06	0.09	0.14	0.23	0.32	3,20
		600	0.35	0.85	1.69	3.04		2,20
		1,000	11.5	34.0				57
	450	25	0.08	0.13	0.16	0.18	0.20	3,20
		50	0.32	0.57	0.89	1.62	2.54	3,20
		100	2.5	4.8	8.6	17.0	42.8	3,20
		200	12.4					25
Coarse 1.4 mm dia.	250	400	0.01	0.01	0.01			1,60
		600	0.01	0.01	0.01	0.01	0.01	3,00
		1,000	0.04	0.04	0.04	0.04	0.04	3,20
		1,200	0.06	0.07	0.08			1,30
		1,600	0.38	0.40				50
		2,000	1.05	1.10				50
	450	50	0.005	0.01	0.01	0.01		2,40
		100	0.02	0.02	0.02	0.025	0.030	3,20
		200	0.01	0.01	0.01	0.015	0.020	3,20
		400	0.09	0.56				60

(*a*) Fractured—general extension 45%. (*b*) Fractured—general extension 26%. (*c*) Fractured—general extension nil.

TABLE 10
Creep and Creep-rupture Tests on 99.0% Aluminium (7)

Temp. °C	Stress lb/in.²	Time in hours for deformation of 0.1%	0.2%	0.5%	1%	5%	10%	20%	Transition to 3rd stage creep h	%	Rupt Tim h
400	1,000			0.1	0.3	1.8	3.0	4.5	1.2	3.0	0
	800			1.5	2.5	10.0	18.0	30.0	7.0	3.0	5
	600		0.35	2.6	7.7	50.0	93.0	>130.0	47.0	4.7	37
	500		9.0	23.0	46.0	197.0	326.0		120.0	2.6	157
	400	18.0	50.0	135.0	264.0	1,150.0	1,700.0		750.0	2.7	408
	300	340.0	690.0	2,400.0 est.							Not br
450	1,000				0.04	0.22	0.4	0.52	0.33	0.9	0
	750			0.03	0.10	1.1	2.0	3.7	0.7	3.2	6
	600			0.5	1.0	4.0	7.2				17
	400	0.8	2.0	4.1	7.6	43.0	91.0				140
	330	2.4	6.0	20.0	50.0	262.0	385.0		125.0	2.1	550
	250	37.0	173.0	1,250.0							Not br

Mechanical properties at 370°C (long soak period)		
0.2% proof stress tons/in.²	Ultimate stress tons/in.²	Elongation %
0.5	0.7	95
0.5	0.7	95
0.9	1.3	60
0.9	1.3	65
1.1	2.2	120
1.1	2.2	120
1.3	1.6	65
1.5	2.2	100
1.5	1.8	75
2.2	2.9	75
1.1	1.8	85
‡*1.7	‡3.6	‡77
‡8.1	‡9.1	‡4
‡6.2	‡7.0	‡2

h	Final Creep rate in./in., h	Duration h
	0	6,000
	0	7,000
	$<0.5\times10^{-7}$	7,000
	0.5×10^{-7}	7,000
	4.5×10^{-7}	7,000
	$<0.5\times10^{-7}$	5,000
	0.5×10^{-7}	5,000
	1.0×10^{-7}	5,000*
	2.0×10^{-7}	5,000
	$<0.5\times10^{-7}$	5,000
	0.5×10^{-7}	5,000
	0.5×10^{-7}	5,000
	1.0×10^{-7}	5,000

h	Duration h	Final extension %
	3,200	0.04
	3,200	0.35
	2,200	3.3
	572	63.0 (*a*)
	3,200	0.2
	3,200	2.7
	3,200	49.0
	250	42.0 (*b*)
	1,600	0.01
	3,000	0.01
	3,200	0.04
	1,300	0.08
	500	0.4
	500	1.1
	2,400	0.012
0	3,200	0.030
0	3,200	0.023
	600	3.7 (*c*)

l extension nil.

p %	Rupture Time h	Elongation %
3.0	0.07	69.0
3.0	5.0	49.4
4.7	37.9	71.0
2.6	157.7	25.0
2.7	408.2	26.7
	Not broken	22.9
0.9	0.57	49.0
3.2	6.0	57.5
	17.1	44.0
	140.2	29.6
2.1	550.5	31.3
	Not broken	

TABLE 11
Reactions of Aluminium with Metals Below 600°C

Solidus	Metal	Melting point °C	Reaction of Aluminium with element
Below 100°C ..	Mercury ..	−38	Solubility small below boiling point of mercury—no compounds.
	Sodium ..	97.5	Small solubility.
	Potassium ..	63.5	
Below 200°C ..	Indium ..	155.4	Small solubility in liquid indium—no compounds.
	Lithium ..	179	Eutectic 179°C (99% Li approx.)—compound Al-Li.
Below 300°C ..	Tin	232	Small solubility in liquid tin—eutectic 229°C (99.5% Sn)—no compounds.
	Bismuth ..	279	Very small solubility in liquid bismuth.
Below 400°C ..	Cadmium ..	321	Insoluble in liquid cadmium below 600°C—no compounds.
	Lead	327	Slight solubility in liquid lead—eutectic 326°C (>99% Pb)—no compounds.
	Zinc	419	Eutectic 382°C (96% Zn).
Below 500°C ..	Germanium ..	958	Eutectic 424°C (53.5% Ge).
	Magnesium ..	650	Eutectic 437°C (68% Mg).
Below 600°C ..	Cerium ..	820	Eutectic 542°C (90% Ce).
	Lanthanum ..	904	Eutectic 542°C (90% La).
	Calcium ..	851	Eutectic 545°C (73% Ca).
	Copper ..	1,083	Eutectic 548°C (33% Cu).
	Silver	960.3	Eutectic 558°C (72% Ag).
	Silicon ..	1,414	Eutectic 577°C (11.6% Si).

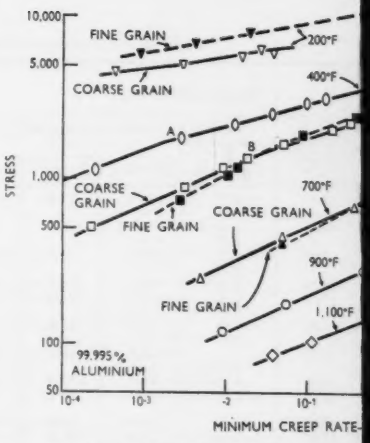


Fig. 11.—Log-log Plot of Stress against
Rate for Pure Aluminiu

TABLE 12
Typical Aluminium Alloys Resistant to High Temperature Water

Composition %							Calculated absorption of thermal neutrons compared to aluminium
Al	Ni	Fe	Si	Cu	Ti	Be	
Bal.	2.5	0.4	0.20				1.22
Bal.	0.75	0.75					1.10
Bal.	1.75	0.75			0.15/0.30	0.005/0.05	1.22
Bal.	1.75	0.75	0.15/0.20		0.15/0.30	0.005/0.05	1.22
Bal.	0.5	0 5	0.2				1.06
Bal.	2.0	0.5	0.2				1.20
Bal.	2.0	0.3	0.1	2.0			1.30
Bal.	0.5	1.0	0.2				1.09
Bal.	2.0	0.5	0.2				1.20
Bal.	2.0	1.0	0.2				1.22
Bal.	0.5	0.5	0.5				1.06
Bal.	0.5	1.0	0.5				1.09
Bal.	2.0	0.5	0.5				1.20
Bal.	2.0	1.0	0.5				1.22

Fig. 14.—Lo
fo

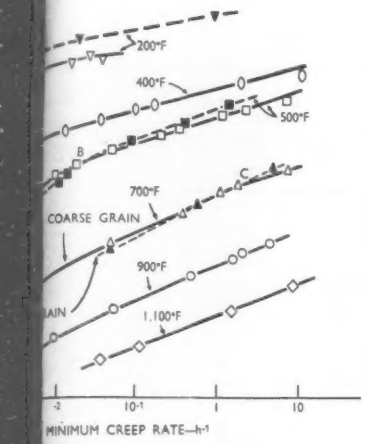
TABLE 13
Approximate Bend Radii for Some Aluminium Alloys (1)

Alloy	State	Radius for 90° bend in sheet of indicated thickness		
		0.016 in.	0.064 in.	0.25 in.
99% Al	Annealed	0	0	0
	Half hard	0	0	1t
	Hard	1t	2t	4t
Al–1.2 Mn	Annealed	0	0	0
	Half hard	0	0	1½t
	Hard	1½t	3t	6t
Al–2.5 Mg–0.25 Cr ..	Annealed	0	0	0
	Half hard	0	1t	3t
	Hard	1½t	3t	6t
Al–4.4 Cu–0.8 Si –0.8 Mn–0.4 Mg ..	Annealed	0	0	1t
	Solution treated—aged R.T. ..	2t	4t	6t
	Solution treated—aged elevated temp.	4t	6t	10t
Al–5.5 Zn–2.5 Mg–1.5 Cu–0.25 Cr–0.2 Mn ..	Annealed	0	1t	3t
	Solution treated	1t	1½t	4t
	Solution treated at elevated temp.	4t	6t	10t

TABLE 14
Effect of Neutron Irradiation on Tensile Properties of Aluminium Alloys (24)

Material	State	Condition	Yield strength lb/in.²	Tensile strength lb/in.²	Elongation %
99% Al	Annealed	Control	6,800± 180	13,600± 320	38.2±3.2
		Irradiated	17,100± 890	26,000±2,000	21.2±1.2
	Half hard	Control	16,600± 250	17,300± 460	6.0±0.6
		Irradiated	24,000± 450	26,000± 380	5.5±1.2
Al–2.5 Mg–0.25 Cr ..	Annealed	Control	14,700± 670	29,200± 450	34.0±3.4
		Irradiated	22,900± 540	37,400± 490	30.6±4.2
	Half hard	Control	29,500± 800	36,000± 700	11.2±2.3
		Irradiated	36,400±1,000	44,700±1,200	14.0±1.1
Al–1.0 Mg–0.6 Si–0.35 Cr ..	Annealed	Control	9,460± 200	18,050± 240	28.8±2.8
		Irradiated	25,600± 460	37,300± 400	22.4±0.8
	Solution treated and aged ..	Control	38,500± 740	45,000± 320	17.5±1.0
		Irradiated	44,400± 670	50,600± 540	16.2±0.7
Al–3.5 Mg–0.25 Cr ..	Cold reduced 50%	Control	47,800± 450	54,700± 500	8.8±1.1
		Irradiated	50,800± 460	57,800± 510	12.5±0.6

Temp. 150°F (66°C). Total irradiation 1.6×10^{21} neutrons/cm² (fast, 10^{20}).



t of Stress against Minimum Creep
or Pure Aluminium.

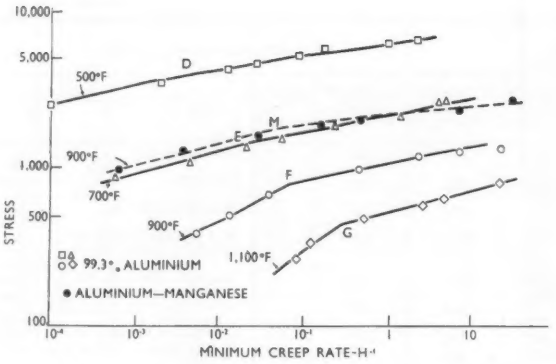


Fig. 12.—Log-log Plot of Stress against Minimum Creep Rate for 99.3% Al and Al—1.2 Mn Alloy.

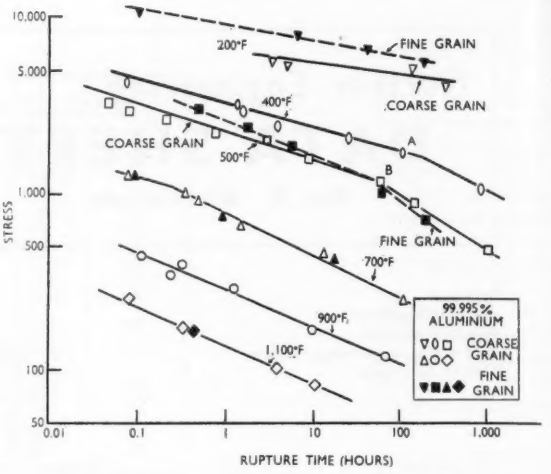


Fig. 13.—Log-log Plot of Stress against Time to Rupture for Pure Aluminium.

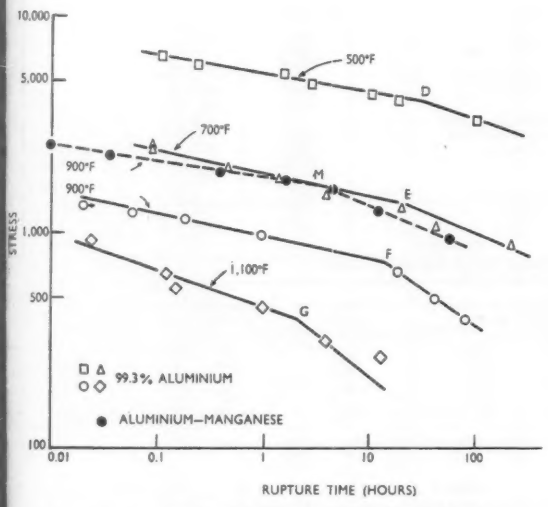


Fig. 14.—Log-log Plot of Stress against Time to Rupture for 99.3% Al and Al—1.2 Mn Alloy.

Fig. 15.—Design Curves for 99.0% Al at 400°C.

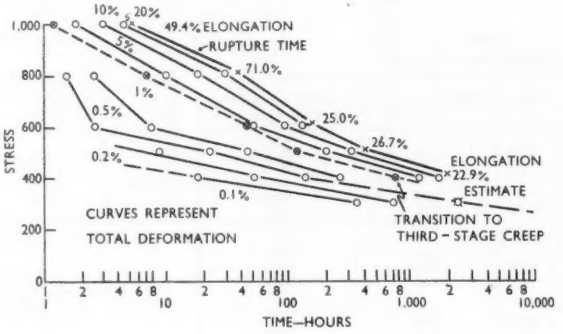
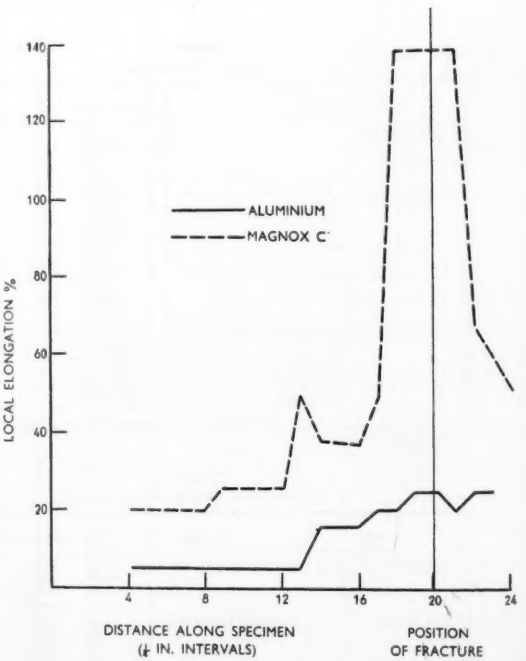


Fig. 17.—Local Elongation Values for Aluminium and Magnox C at 350°C. Time to Fracture 1,000 h.



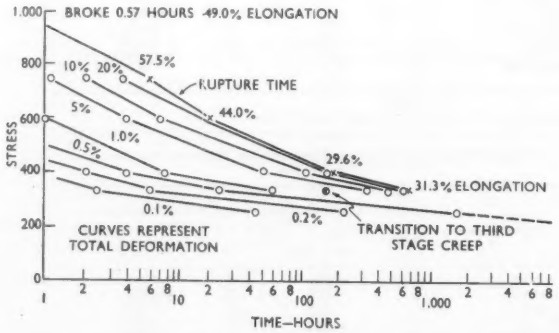


Fig. 16.—Design Curves for 99.0% Al at 450°C.

Technical Papers and Publications

THE INSTITUTE OF METALS

Spring Meeting in Conjunction with the BNEC

Discussion on the life of Fuel Elements

The Chairman, Dr. Finniston (Harwell), stated that the discussion would be led by a number of invited speakers representing the principal laboratories engaged in research in the relevant fields. Opening the discussion, Professor J. G. Ball (R.S.M.), drew attention to the principal factors likely to influence the life of the fuel elements.

Dr. A. B. McIntosh (Culcheth) discussed the subject of thermal creep of alpha uranium, pointing out the great influence of factors such as grain size and minor compositional changes on the creep strength. By comparison with some results for low carbon steel and a high purity aluminium alloy, the effect of grain size was shown to follow the general pattern to which other alloy systems conformed. The effect of the minor compositional variations was demonstrated by results for both calcium and magnesium reduced metal. Creep data were also presented for a wide range of dilute uranium alloys at 400° and 500°C, and for grain size controlled magnesium reduced uranium from 400° to 600°C. The results for the latter were shown to be well represented by the equation

$$\dot{\varepsilon} = 5.02 \times 10^{6} \exp.\ (40{,}100\sigma^{1.70}/RT)$$

obtained by statistical analysis of the whole of the data.

Fig. 1 shows the experimental points and the plot of the equation for three temperatures. Dr. McIntosh also reported both theoretical and experimental work on the effect of small continuous thermal cycles on the creep strength showing that at stresses of the order of those existing in the Calder reactors relatively small continuous cycles reduced the creep strength by as much as a factor of three at 500°C. Monsieur Bernard (Saclay) supported Dr. McIntosh's emphasis on the effect of minor variations in composition, changes in thermal history and grain size on the creep strength, and gave examples of the variations produced.

Dr. G. B. Greenough (Windscale) discussed the irradiation growth of uranium. In the case of a single crystal the 010 axis expands and the 100 axis contracts, while the 001 axis remains unchanged. The actual growth rate is exponential, the crystal doubling its length for a burn-up of 0.2% (~2,000 MWd/t). During irradiation in a polycrystalline aggregate each crystal tries to change its dimensions, but is restrained by its neighbours. The net result has two aspects:—

(1) Preferred orientation, e.g., a bar rolled at 300°C (010 along the bar) leads to elongation of the bar.

(2) The surface of the bar deforms to produce an orange peel effect. The Windscale Laboratories have devised a wrinkling parameter to measure this surface distortion, and Dr. Greenough showed a slide giving the variation with temperature.

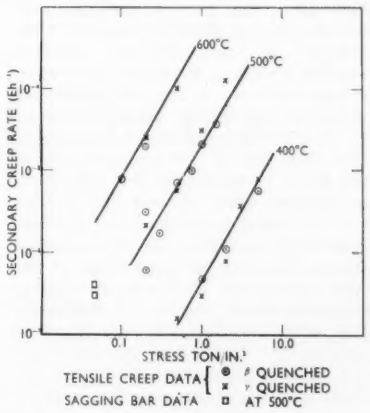


Fig. 1.—Tensile creep data for uranium.

Both effects could lead to rupture of can materials with limited ductilities, and as the surface wrinkling is related to the surface grain size fine-grain material with no preferred orientation is essential for fuel elements with long lives. As Fig. 2 shows, the wrinkling parameter is a maximum at round about 200°C, falling off slowly at lower temperatures, and more rapidly at the higher temperatures. Available evidence suggested that alloying additions below the level required to alter crystal structure had little effect on irradiation growth rates.

Mr. A. C. Roberts (Harwell) described theoretical and experimental studies on the effect of irradiation on the creep of uranium. Irradiation growth led to the development of inter-granular stresses which, in conjunction with the applied load produced, accelerated creep at a rate shown theoretically by Cottrell and Roberts to be of the order of one or two elastic deflections per week. For example, under a stress of 1,000 p.s.i. at 100°C the calculated creep rate was 10^{-10} sec^{-1}, whereas in the absence of irradiation the creep rate would be negligible. Subse-

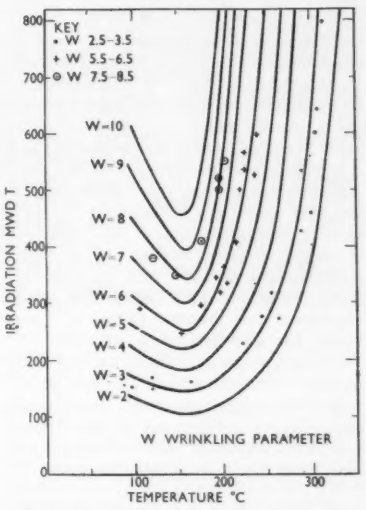


Fig. 2.—Irradiation achieved against temperature for various wrinkling parameters.

quent experimental work on helical springs of natural uranium on a flux of 113×10^{12} thermal neutrons/in^2,sec confirmed the order of magnitude of the theoretical predictions. In addition to this steady state creep, transient effects occur at the start of irradiation and when the neutron flux is removed.

Discussing swelling, Dr. Churchman (A.E.I.), expressed the view that the form of radiation damage most likely to limit the life of the fuel element is the accumulation of the gaseous fraction of the fission products, particularly as the operating temperatures are increased. To achieve the objective of 3,000 MWd/t for the first round of civil reactors, accommodation has to be found for a volume of insoluble fission gas product equal to some four times the volume of the fuel at its operating temperature of 450°C. Experimental results on the swelling of the fuel due to the fission gas products were few and showed a very large scatter. Observations which conclusively laid the blame for the observed swelling on the gaseous fission products were:—

(1) Up to about 10% swelling, the volume of voids was approximately the same as the volume increase.

(2) For a restricted number of pressure cycles of up to 6,000 p.s.i. nearly reversible changes in density are produced.

Existing unsatisfactory theories of swelling were based on the creep strength of uranium. All theories made no allowance for surface tension forces or

cracking in an embrittled matrix. Experimentally large numbers of voids of less than $\frac{1}{4}$ μ diameter could be detected in which the surface tension forces are much greater than the yield stress of the matrix, and in post irradiation heating at least, large swelling occurs on internal cracking or at inclusions. Dr. Churchman expressed the view that there were five approaches to limit the restriction placed by swelling on fuel element life:—

(1) Use a small restraining force to direct the swelling in an acceptable direction.

(2) Maintain a full restraining pressure greater than 6,000 p.s.i.

(3) Produce a fuel containing *only* a stable dispersion of 1/10 μ particles on a lattice of $\frac{1}{4}$ to $\frac{1}{2}$ μ pitch, in which case the gas may tend to nucleate into small bubbles retained at very high pressure by surface tension forces.

(4) Adopt a fuel material with an isotropic structure in which anisotropic irradiation and thermal effects will not reduce the effective creep strength.

(5) Use enriched ceramics such as UO_2 of high strength which are known to resist swelling to high burn-ups. A high initial density is necessary to ensure that a definite swelling problem does not arise from gas release into the can.

Mr. S. F. Pugh (Harwell) discussing the growth of uranium on slow thermal cycling in the alpha phase showed uranium bars after cycling 850 times between 50 and 600°C, illustrating that coarse grain leads to wrinkling, preferred orientation leads to growth. Beta quenching refines the grain size and removes most of the preferred orientation but a portion of the latter remains causes warping on cycling due to slight differences in texture in different sections of the bar. A cast bar is free from preferred orientation. American work on the mechanism of growth on cycling has shown that this is due to a combination of three factors:—

(a) Anisotropic thermal expansion of alpha uranium single crystals.

(b) The presence of a double texture in rolled uranium.

(c) The change in the modes of plastic deformation with temperature in the cycling range.

Work at Harwell has shown:—

(a) How the experimental results relating growth to the time and temperature at the upper holding temperature can be analysed to give an activation energy equal to that expected for self diffusion in uranium.

(b) How the internal differential expansion is distributed quantitatively.

(c) How analysis based on bi-crystal models can be related to polycrystalline aggregate.

Discussing cycling through the alpha/beta phase change, Dr. M. B. Waldron (Harwell) showed that the effects were change of shape, surface splitting, the formation of sharp pimples, and the production of internal voids. The terminology applied to neutron irradiation damage was also applicable "growth" being defined as change of shape, and "swelling" to increase in volume due to the formation of internal pores. Earlier experimental work and the hypothesis arising from this work were briefly covered. It had been concluded that the passage of a phase interface through the bar occurred even under nominally isothermal conditions. In these circumstances the greater strength of the beta phase taken in conjunction with the ~1% volume change on transformation constrains the alpha phase to distort. In some experimental work carried out to examine this hypothesis, specimens were held between copper blocks and subjected to both longitudinal and transverse temperature gradients. In all cases the deformation pattern was determined by the direction of the temperature gradient and not by the geometry of the uranium specimens. The rate of initiation and deformation was shown to depend on the porosity of the uranium, sintered material having a negligible incubation period in contrast to the long incubation period of high-density swaged material. Dr. Waldron reported calculations of the stress field due to a cylindrical core of beta phase in the centre of a cylindrical fuel element which showed that at least $\frac{1}{3}$ of the diameter would have to transform to the beta phase before the surface stresses exceeded the yield stress of the alpha phase and thus allowed cycling damage to occur. In fact, in Waldron's view with a radially moving interface independent relaxation of the alpha and beta phases could not occur and the effects would probably remain reversible until the phase interface closely approached the surface of the fuel.

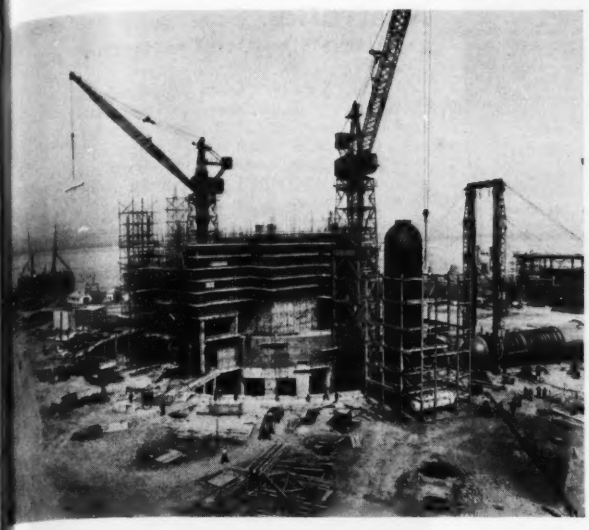
In the second half of the discussion devoted to the canning material, Dr. W. E. Dennis (G.E.C.) opened by pointing out that the values generally accepted for the mechanical properties of Magnox A.12 were such that, by sensible design, cans could be produced requiring less than the maximum properties of the A.12. This argument, unfortunately, only applied to the gross mechanical properties and the gross design strains. The determining factor in can failure was the inability of the ductility available in a small area to meet the strain in that same area, thus the minimum ductility in any small area and the maximum strain were the pertinent factors for with 60,000 cans in a reactor, opportunities for coincidence were considerable. Dr. Dennis then showed the variation in ductility for five bars taken from different casts, and also an extreme example of the spread of ductility obtainable in a single bar. With extruded, rather than machined cans, there would be a smaller range of properties, but in his view we should still be very concerned with both directional and positional variation of properties. He suggested that the problem could be tackled in three ways, first by designing to avoid strain raisers, second by closer control of manufacturing procedures, and third by searching for a better alloy with a greater margin of properties above the required minimum.

Dr. Littlejohn (Atomic Power Projects) discussing corrosion resistance, gave a typical oxidation curve for Magnox alloys and expressed the view that all magnesium alloys were probably satisfactory from the oxidation point of view for temperatures for which it was feasible to use Magnox cans. He stressed the need to avoid anodic couples due to impurities and therefore the need for close control of production.

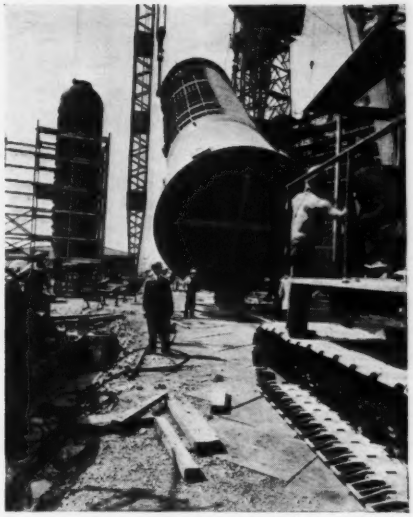
Dr. M. J. Makin (Harwell) discussed the effect of irradiation on the properties of magnesium alloys. Tensile tests carried out on material previously irradiated to an integrated dose of 10^{20} nvt at 50°C in an attempt to avoid annealing effects had shown no significant change. He reported that calculations showed that the rate of vacancy production due to the neutron flux became less than that due to thermal agitation for magnesium at temperatures in the range 100°/200°C, it was, therefore, not surprising that the experiments he reported had provided no evidence of irradiation damage.

Dr. A. G. Knapton (A.E.I.) discussed zirconium and beryllium as possible alternative canning materials to magnesium. The mechanical properties and the thermal neutron cross-section of zirconium were good but the thermal conductivity so poor that in his view it could be dismissed. Beryllium possessed excellent conductivity and a small absorption cross-section but the mechanical properties were inferior, the minimum ductility at 600°C being 0.5%. It was incompatible with uranium above 550°C and also incompatible with a number of circuit materials. In his view alternative canning materials should be considered, particularly stainless steel and niobium.

In the limited time available for open discussion, Dr. J. M. Alexander (Imperial College) made the point that the usual stress analysis of the bowing of a fuel element ignored the properties of the magnesium can. His analysis indicated that the magnesium can actually increases buckling life by a factor between two and five depending on the temperature. Dr. G. E. Darwin (Babcock and Wilcox) argued that to assume that an increase of temperature of operation increased efficiency was not necessarily valid. Optimization of conditions could well indicate that the longer fuel element life obtained at a reduced temperature gave higher overall efficiency. Mr. L. M. Wyatt (Risley) discussed the problem of achieving the design burn-up of 3,000 MWd/t in the first civil reactors, and stated that on available evidence he had confidence that this could be achieved.



(Left) This recent photograph taken at Berkeley shows No. 1 reactor under construction. In left background can be seen the coffer dams for the intakes through which water will flow at the rate of 21 million g.p.h. to cool the condensers.



(Right) Berkeley's second heat exchanger was lifted into position on May 21. The boilers for Berkeley are being fabricated on site by John Thompson.

World News

International

U.S. OFFER TO EURATOM

Euratom has accepted without reservation an American offer to finance the purchase of 1,000 MW of U.S.-built power reactors. Mr. Louis Armand, president of the Euratom commission, will probably visit Washington shortly to initial a formal treaty. As a first step, the U.S. has offered a credit of $135 million which will enable Germany, France, Italy and Benelux each to install 250 MW U.S. power reactors. The terms of the loan have not been officially announced but they are believed to be 3¼% for a period of 12 to 20 years. In addition the U.S. has indicated a willingness to contribute $10 million a year towards a joint programme of research and development providing Euratom contributes a similar sum.

A possible difficulty over the proposed treaty is the A.E.C.'s ruling that the Euratom countries must allow international inspection of any power reactors built. Euratom insists that this would infringe the sovereignty of the nations involved.

U.K.-U.S. COLLABORATION:

The recent visit to the United States of the Prime Minister, Mr. Macmillan, and the A.E.A. chairman, Sir Edwin Plowden, sparked off the usual series of rumours that (a) Britain was withholding information on Calder Hall and (b) that one of the objects of the visit was to obtain a Nautilus reactor for the U.K.'s Dreadnought submarine. So far as the first point is concerned, an official spokesman for the A.E.C. said on June 12 that there had been a "misunderstanding" on the scope of the information that Britain was required to supply to the U.S. This has now been clarified and full information on the Calder Hall fuel elements will now be made available to the U.S. Speculation on the submarine was answered by Lord Selkirk, First Lord of the Admiralty, who, on June 11, told the Lords that a number of difficulties could be overcome if U.S.-built machinery, design information and manufacturing know-how could be obtained. The Government had therefore asked the U.S. Government if it could purchase a complete American nuclear submarine propulsion unit.

EURATOM AND THE U.K.

Mr. R. A. Butler told the Commons on May 22 that the British Government was hoping to negotiate an agreement with Euratom shortly. Following his remarks it was announced that Sir William Meiklereid, the head of the U.K. delegation to the High Authority of the European Coal and Steel Community, had been appointed representative to the European Atomic Energy Community. Euratom has already agreed to begin talks with the British Government.

EFFECTS OF RADIATION

The U.N. report on the effects of atomic radiation is now in its final approved form following a series of meetings of the scientific committee during June. The final report is expected to be passed to the various governments in July. It will cover both the immediate effects of radiation and the long-term effects on future generations.

Dungeness has been chosen as a prospective site for a nuclear station. Providing approval can be obtained, a 500 to 550 MW plant will be erected on the barren shore to the west of the lighthouse.

Denmark's nuclear research centre at Risö was officially opened on June 6.

International

PREPARATIONS FOR GENEVA

The second Atoms for Peace conference and exhibition (Geneva, September 1-13, this year) will be on a far larger scale than the first conference three years ago. So far the U.N. has received nearly 2,400 abstracts of papers from 45 governments and four agencies compared with 1,067 presented by 38 governments and five organizations in 1955. The average length of each paper is 21 pages, an increase of over 40%. Before the conference opens some 220 million pages of abstracts and papers weighing a total of 550 tons will have to be printed. The papers selected will be presented in 77 sessions, as compared with 55 in 1955.

HANDLING ISOTOPES

Scientists from ten countries have been asked to assist the International Atomic Energy Agency in drawing up general health and safety recommendations to govern the packaging, transport, use and disposal of radioisotopes. Dr. Gunnar Randers (Norway) is chairman of the panel.

United Kingdom

DMTR CRITICAL

Dounreay Materials Testing Reactor went critical on May 24. DMTR has been built by Head Wrightson Processes and is basically similar to PLUTO at Harwell.

FIRST BRADWELL BOILER ARRIVES

As briefly reported last month, the first of the Bradwell heat exchangers was towed to the site by sea from Head Wrightson's Thornaby works. At Bradwell waterside the 200-ton boiler was lowered by the tide onto two 16-wheel bogies. The load was then towed to the site by road, a distance of about 1¼ miles. The Goliath crane was subsequently used to erect the heat exchanger. The remaining eleven boilers will be delivered to the site in the same way at monthly intervals.

More than 200 delegates representing 80 companies attended a confidential conference on reactor technology at A.E.R.E. Harwell on June 11.

The scene at Bradwell waterside shortly after the arrival by sea of the first heat exchanger.

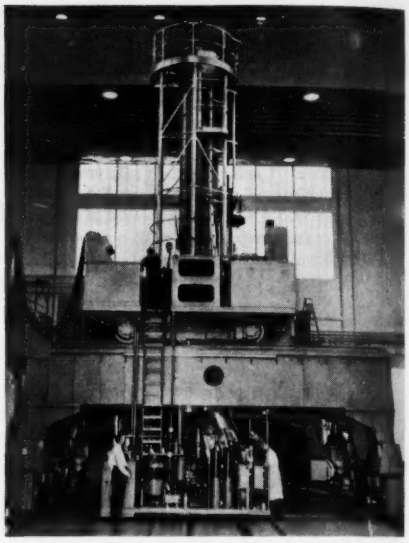
Australia

RADIOACTIVITY DAMAGES: APPEAL FAILS

Victoria Supreme Court dismissed an appeal by the Commonwealth Government against an award of £24,532 damages to Mr. John Thoonen, a Dutch migrant. His right leg was amputated after he had carried in a pocket of his overalls for a week, a radioactive capsule which he picked up at work in a power house in 1955.

NUCLEAR SYMPOSIUM

About 400 scientists and engineers—including 40 technologists from Britain, America and Canada—were present at the first Australian nuclear symposium and exhibition in Sydney. More than 100 papers were presented. Twenty-one international and Australian organizations were represented at the concurrent nuclear exhibition.



Fuel charge and discharge machine for Canada's NRU reactor.

Belgium

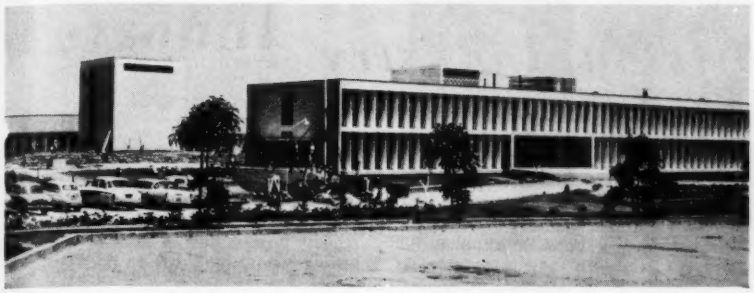
U.S. REACTOR GRANT

A contribution of $350,000 is being made by the U.S. towards the cost of a research reactor at the Belgian Centre d'Etudes de l'Energie Nucleaire (C.E.N.) at Mol. The reactor involved is a 50-MW water-cooled and moderated, pressurized, tank-type, materials testing facility designed by the Nuclear Development Corporation of America and constructed by a consortia of Belgian and U.S. concerns. The U.S. will also supply the necessary enriched uranium; estimated completion date is the end of 1959.

Canada

NRU FUEL ELEMENT FIRE

A fuel element caught fire as it was being removed from NRU recently. An official announcement from Atomic Energy of Canada said that although the fire was quickly extinguished, radioactive dust contaminated the interior of the building. The reactor has been shut down for several weeks so that the 12-storey building can be decontaminated.



Israel's new nuclear institute at [Rehovoth was opened on May 20. A 3 MeV Van de Graaff proton accelerator is housed in the tower on the left.

Czechoslovakia

LITERATURE FOR I.A.E.A.

The first of a regular supply of technical documents from the central technical library to the I.A.E.A. was handed over by Ambassador Pavel Brinkler recently.

Denmark

NUCLEAR CENTRE OPENED

Denmark's first nuclear research station at Risö, a small peninsula in the Roskilde Fjord, was opened on June 6. Among the guests were King Frederik and Queen Ingrid and many foreign scientists, including Sir John Cockcroft. Professor Niels Bohr, chairman, Danish A.E.C., spoke during the inauguration. So far Risö has cost nearly £5 million. Of the three reactors planned, only the first, DR1, a 5-kW test reactor, is in operation. DR2 has been delayed because of leaks in the reactor tank supplied by the U.S. The third Danish reactor will be a heavy-water moderated PLUTO supplied by Head Wrightson Processes.

Formosa

REACTOR GRANT FROM U.S.

United States will contribute $350,000 towards the cost of a 1-MW (T) heterogeneous water-cooled and moderated pool-type facility designed and built by International General Electric. The reactor will be located at the Institute of Nuclear Science, of National Tsing Hua University, at Hsinchu, about 40 miles south-west of Taipei, Taiwan.

Israel

NUCLEAR INSTITUTE OPENED

Israel's new nuclear science institute, forming an integral part of the Weizmann Institute at Rehovoth, was inaugurated on May 20. The largest centre for nuclear research in the Middle East, the building covers an area of some 7,000 sq. metres. It houses the Weizmann Institute's departments of nuclear physics, isotope research and electronics as well as the infra-red spectroscopy and nuclear induction laboratories. A 3-MeV Van de Graaff proton accelerator is associated with the department of nuclear physics.

Following the inauguration, Professor Sir Christopher Ingold, professor of chemistry, London University, was made an honorary fellow of the institute for his leading part in creating the theoretical structure which transformed organic chemistry from an empirical into an exact science.

Italy

SENN-A.E.A. DISCUSSIONS

Società Elettronucleare Nazionale (SENN) and a mission from U.K.A.E.A. had discussions in Rome on May 20 concerning problems arising from the supply of nuclear fuels and the related guarantees.

Euratom Commission next meets in Rome from June 25 to 30. Eurochemic steering committee will also hold a series of meetings in Rome during the previous week.

Kenya

URANIUM ORE SURVEY

Radiometric aerial survey for uranium over 4,000 square miles of the Coast Province of Kenya is being undertaken by the Authority in conjunction with Hunting (Geophysics). A Percival Prince equipped with a scintillation counter developed by Harwell is being flown at low level over the area.

New Zealand

NUCLEAR PROGRAMME OUTLINED

The Government proposes to establish an institute of nuclear science and also to buy an atomic particle accelerator. A team of U.S. scientists who recently visited the country concluded that New Zealand was not yet in a position to support a nuclear power programme or to purchase a nuclear power station.

Norway

U.S.S.R. NUCLEAR EXHIBITION

An exhibition featuring peaceful uses of nuclear energy in the U.S.S.R. is to visit Oslo this summer. The material will be divided into five sections showing all stages of development—from mining uranium to the operation of reactors. The applications of radioisotopes in industry, biology and agriculture will also be described.

Spain

NUCLEAR ADVISERS NAMED

Internuclear Company has been retained by Centrales Nucleares del Norte, S.A., Nuclenor, to conduct preliminary studies on plans to build a nuclear powerplant of 220 to 250 MW (E) in N. Spain. Nuclenor is a consortia of Spanish utility companies: Internuclear are already looking for possible sites for a station.

United States

REACTOR FOR GENEVA

TRIGA, a 10 kW multi-purpose research reactor developed by General Atomic Division of General Dynamics, will provide short-lived radioisotopes for the U.S. Government exhibit at the second Atoms for Peace conference at Geneva this year.

FOOD IRRADIATION

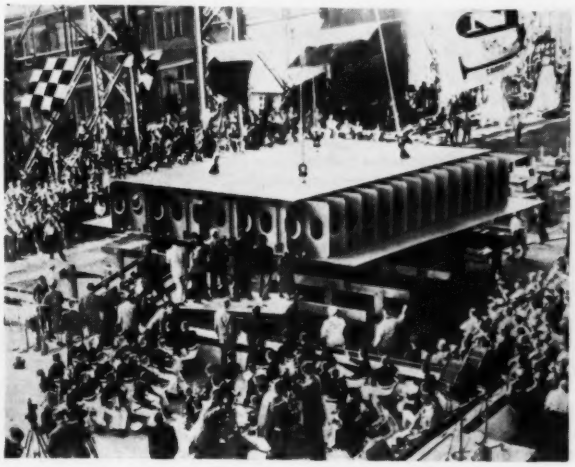
Fifteen companies have submitted proposals to the A.E.C. for a cobalt 60 gamma food irradiator. The facility, to be known as HIFI (High Intensity Food Irradiator) will be used by the Army Quartermaster Corps in connection with its food preservation project at Sharpe General Depot. Previously it was planned to build a reactor for irradiation but the project was dropped some time ago. The source of radiation now envisaged will be about 2 million curies of cobalt 60.

U.S.S. Skipjack—the third nuclear submarine—was launched on May 26 at the shipyards of Electric Boat Division, General Dynamics Corporation. Skipjack is to be powered with a Westinghouse reactor. The vessel is designed for underwater speeds in the region of 40 knots.

U.S.S.R.

SYNCHROCYCLOTRON MODIFIED

Partial reconstruction of the high frequency synchrocyclotron system has been completed at the Joint Nuclear Research Institute at Dubna, near Moscow. It is now possible to change rapidly from the acceleration of one type of particle to a completely different type. Deuterons can be accelerated up to 420 MeV and alpha particles up to 840 MeV.



Keel plate for the N.S. Savannah was lowered into position at New York Shipyards on May 22. Mrs. Richard M. Nixon, wife of the U.S. vice-president, operated an electronic triggering device to set the crane in motion.

Orbits in Industry

THE general situation regarding U.S.-U.K. exchange of information still seems a bit tricky, owing to the completely different conditions obtaining. Fuel element design particulars are largely the property of commercial concerns and the A.E.A. can hardly hand them over to be broadcast, otherwise the situation becomes like that of censorship during the war, when news could be cabled immediately to the States, but had a later release date in the U.K. This difficulty used to be solved by the solemn farce of transmitting the news to the U.S. and having it cabled back again, when it was lawful to publish it, as having come from an outside source. Will the same rules apply?

We must not lose sight of the fundamental difference in outlook as well as in conditions. In the U.S., "declassification" means freedom to publish the lot; song, dance *and* patter. In the U.K. it means, in effect, "You may make inquiries without being arrested under the Official Secrets Act. If you are sufficiently persistent and thick-skinned, you may have the information if (a) you can find somebody who isn't frightened to tell you, (b) we aren't saving it for a Geneva paper, (c) we can't think up a good excuse for invoking Commercial Security."

"No Reporters, Please"

This fulmination, from a normally easy-going bloke like Tangent, sounds as though the A.E.A. were accused of discrimination against the Press. So, in fact, they are. A recent invitation to see a certain industrial process being carried out on a site owned by the A.E.A. had to be cancelled at the last minute. It had been made quite clear by the A.E.A. that they had no objection to the manufacturer in question taking along a party of customers or, for that matter, anyone they felt like—*except members of the technical Press.*

Once more, it should be pointed out that this is not intended as criticism of those whose job is Press liaison. They do as good a job as anyone could with their hands tied. But as long as the A.E.A. cling to the more sinister implications of "autonomous" divisions, and each of these miniature empires—all convinced that they themselves are the pivot around which the Authority really revolves—is free to formulate its own policy of relations with the outside world, the Boron Curtain, to which previous reference has been made in these columns, will continue as a barrier, not only to information but to mutual understanding.

Pimple Welding

Latest example of an undesirable effect being turned to good use is the development by the British Welding Research Association of the splashing that occurs when spot welding with too high a current. By using a recessed upper electrode and a small hole in the upper workpiece, the splash is forced into the electrode recess and solidifies as an attached "pimple" which, providing it is not undercut, can be almost any shape, and can even have an insert included. A weld with an alumina thermocouple block recessed into it was one of the interesting exhibits at the annual exhibition of the British Welding Research Association. The laboratories have already been described (*Nuclear Engineering*, September 1957, p. 386) on the occasion of their official opening; and the importance of their work was stressed by Sir Claude Gibb, speaking at the luncheon, when he pointed out that the studies being carried out on brittle fracture alone might have a considerable effect on nuclear development.

Bouquet for Babcocks

Imitation, we are told, is the sincerest form of flattery, but the reverse is occasionally nearer the truth. If the heat exchangers in the ORNL study (page 281, this issue) had been a lifelike copy of those for Calder Hall, it would have been a sincere compliment for Babcock and Wilcox, yet the fact that they are utterly and completely unlike them is, in reality, even more of a tribute to the standard of workmanship. The ORNL report laconically states that . . . "even with the large number of tube-to-header joints employed in the Calder Hall heat exchangers (35 times as many as the ORNL design) no tube-to-header joint leakage has occurred in more than a year of operating experience. . . ." They have, therefore, put the joints inside the vessel, and simplified the design. Could there be a more flattering testimonial?

Guest Star

Through a mutual friend, Tangent has made the acquaintance with the eminent Dr. Aloysius Plantagenet Finagle, who has spent a considerable amount of time and research (commonly known as "finagling") on the formulation of the natural laws governing phenomena with which most of us have become acquainted without realizing that they were by no means isolated incidents. In some respects his work resembles that of an eminent scientist with a monosyllabic name, whose First Law ("Whatever effect is causing discrepancy in experimental results, radiation will make it worse") is quoted by research workers from Harwell to Halifax.

Finagle's Laws refer more to practical engineering design and, since they appear worthy of a wider public, the Doctor will appear as a guest star on this programme. Since, however, his work has been so widespread, there may be some difficulty in compiling a complete—or even truly representative—collection. Should any readers possess any of his earlier manuscripts, would they care to donate them?

DR. FINAGLE'S LAWS—1

Law of the Too, Too Solid Point

In any collection of data, the figure that is most obviously correct—beyond all need of checking—is the mistake.

Corollary I: *No one* whom you ask for help will see it either.

Corollary II: *Everyone* who stops by with unsought advice will see it immediately.

Isotopiana

Ceremonial openings nowadays appear to have deserted the silver key or the golden scissors, and been brought up to date, with a spot of isotope and a counter, so that the waving of a magic wand will trigger off the effects that declare the bazaar to be well and truly laid. With the present trend towards replacing superstition by science, we can see, in the interests of the younger generation, the rewriting of all our fairy stories and, of course, pantomimes. The kitchen scene from Cinderella, for example, might go something like this:—

Fairy Queen
Now, Cinders dear, don't give up hope,
I just uncork this isotope
And, in the twinkling of an eye,
What should have been a pumpkin pie
Becomes a lovely golden coach
Of workmanship beyond reproach.
No Woolworth stuff; but in the class
Of Hooper*, Ward*, or Van den Plas*
And now, some mutagenic mice
In point oh-one of half a trice
Turn—bucking broncos, full of beans!
(It must have been the cowboy genes)
How's that for fast mutation, chums?
But hush! the King of Demons comes.

(Enter the Demon King)

F.Q.—What mean you by this knavish trick?

D.K.—I got this gun from Metro-Vick*
This small accelerator linear
Will soon pump fast electrons in yer!
And so I'll foil your little plot—

F.Q.—Don't point that thing at me, you clot!
You think to scare me—I'm surprised;

D.K.—You'll soon be cross-polymerized.

F.Q.—You cannot hope to win, of course
Like racing men . . . I gotta Source!
Bolonium-terwillium—well—
The latest thing from I.D.L.*
Die, villain, as I tell you that
Its spectral curve is NEARLY FLAT!

(CURTAIN)

One of the advantages of this, of course, is that it offers itself as an admirable medium for short commercials and the asterisks indicate suitable spots for inserting "plugs." If any publicity managers are interested, will they please communicate in person. Used pound notes, please—no cheques.

Tangent

Personal

Sir W. Meiklereid.

Mr. P. T. Fletcher.

Mr. H. V. Disney.

Mr. R. V. Moore.

Appointments

Sir William Meiklereid, head of the U.K. delegation to the High Authority of the European Coal and Steel Community, as the British Government's representative to Euratom.

Mr. P. T. Fletcher, formerly director of engineering, becomes deputy managing director, Industrial Group, U.K.A.E.A. **Mr. H. V. Disney,** formerly deputy director, defence plants, supplies and services, becomes director of engineering. **Mr. R. V. Moore,** formerly deputy director, civil reactors, becomes director of reactor design.

Mr. Lewis Strauss, chairman, U.S.A.E.C., will not be reappointed for a further term of office. An announcement from the White House on June 5 said that he will continue to advise President Eisenhower on atomic affairs. **Mr. John McCone** has been nominated as the fifth member of the commission.

Sir William Holford has been reappointed a part-time member of the Central Electricity Generating Board.

Sir A. Forbes.

Mr. J. Bell.

Mr. J. Bell, B.Sc., F.Inst.P., as manager of the G.E.C. research laboratories at Wembley.

Sir Archibald Finlayson Forbes, G.B.E., as a director of English Electric.

Vice-Admiral Sir Frank Mason, K.C.B., M.I.Mech.E., M.I.Mar.E., succeeds Sir Andrew McCance, F.R.S., as chairman of the Mechanical Engineering Research Board.

Mr. J. H. Ross, as managing director of Chamberlain and Hookham, in succession to **Mr. J. S. Carter,** who has retired.

Mr. K. H. Frostick has recently assumed the responsibilities of sales manager of Plessey's chemical and metallurgical division at Towcester, Northants.

Mr. E. W. Tandy as a director of J. Day and Co. (Derby Works).

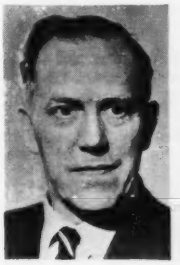
Mr. J. W. Bennett, recently president Atomic Energy of Canada, as general manager of Canadian British Aluminium Co. in succession to **Mr. P. T. Ensor** who is returning to the U.K. in July to take up other duties.

Mr. P. H. Dunn, M.A., who, for the past four years has been the Babcock and Wilcox representative in New York, as assistant sales manager of the company. **Mr. T. S. Blackadder** becomes Babcock's representative in New York.

Dr. E. R. Patrick, head of North Staffordshire Technical College's engineering dept., succeeds **Dr. H. W. Webb** as principal on October 1.

Mr. T. P. Everett, formerly managing director, Richardsons Westgarth (Hartlepool), becomes executive director of Richardsons Westgarth. Based at London, he will deal with the company's atomic business together with **Mr. H. Fothergill,** the company's consultant on atomic affairs. **Mr. H. Watson-Jones** becomes managing director at Hartlepool; he is also elected to the board of the parent company.

Mr. Alex Abel Smith, T.D., J.P., succeeds **Major Desmond Abel Smith,** M.C., as chairman of the Bryan Donkin Co. **Mr. R. T. Redfern,** M.I.Mech.E., M.Inst.Gas.E., managing director, becomes vice-chairman, and **Vice-Admiral Sir Conolly Abel Smith,** K.C.V.O., C.B., becomes a director. **Mr. R. Hutchinson,** M.Inst.Gas.E., is appointed technical sales manager at Chesterfield. **Mr. B. I. Stone,** A.M.Inst.Gas.E., will continue to operate from the London office.



Mr. S. Brewer.

Mr. R. Hutchinson.

Mr. S. R. B. Brewer, B.Sc.(Eng)., A.M.I.E.E., as a director of Bryce Electric Construction. He was appointed sales manager in 1955.

Mr. Charles P. Yerkes as nuclear sales engineer, Vitro Engineering Co.

A.E.A. Groups Reconstructed

U.K.A.E.A. have announced the reconstitution of the governing bodies of the three Groups.

RESEARCH GROUP

Membership: Chairman, **Dr. B. F. J. Schonland,** director; **Mr. D. W. Fry,** deputy director; **Mr. J. R. V. Dolphin,** chief engineer; **Dr. R. Spence,** chief chemist; **Dr. H. M. Finniston,** chief metallurgist; **Dr. J. V. Dunworth,** head of reactor division; **Mr. D. R. Willson,** technical secretary; **Mr. T. B. Le Cren,** general secretary; **Mr. J. C. C. Stewart,** industrial group member; **Dr. S. C. Curran,** weapons group member; **Mr. J. A. Jukes,** London office member.

INDUSTRIAL GROUP

Membership: Chairman, **Sir Leonard Owen,** managing director; **Mr. J. C. C. Stewart,** deputy managing director; **Mr. P. T. Fletcher,** deputy managing director; **Dr. H. Kronberger,** director of research and development; **Mr. J. B. W. Cunningham,** director of industrial power; **Dr. R. Hurst,** director of Dounreay; **Mr. K. B. Ross,** director of operations; **Dr. A. S. McLean,** director of health and safety; **Mr. D. S. Mitchell,** director of personnel and administration; **Mr. D. R. Newman,** director of finance; **Dr. H. M. Finniston,** research group member; **Mr. G. L. Hopkin,** weapons group member; **Mr. J. A. Jukes,** London office member.

WEAPONS GROUP

Membership: Chairman, **Sir William Penney,** director; **Admiral P. W. B. Brooking,** assistant deputy director; **Mr. G. L. Hopkin,** chief of materials; **Mr. E. F. Newley,** chief of warhead development; **Mr. C. Adams,** chief of trials and safety; **Dr. S. C. Curran,** chief of nuclear research; **Mr. J. M. High,** head of engineering services; **Mr. J. E. Adamson,** group secretary; **Dr. B. F. J. Schonland,** research group member; **Mr. J. C. C. Stewart,** industrial group member; **Mr. A. E. Drake,** London office member.

Dr. L. W. Brown, B.Sc., Ph.D., M.I.E.E., F.Inst.P., as assistant chief electrical engineer (light current), Metropolitan Vickers Electrical, in addition to his present duties as chief engineer electronics dept.

Mr. Ralph O. Hutchison as assistant to General Walter Bedell Smith, vice-chairman, American Machine and Foundry Co.

Dr. James H. Jensen, provost, Iowa State College, as the first president of Associated Mid-West Universities. **Dr. Laurence L. Quill,** professor and head of the chemistry department at Michigan State University becomes vice-president of A.M.W.

Mr. Arthur N. Anderson as assistant vice-president, and **Mr. Gordon R. Milne** as chief mechanical engineer of Consolidated Edison of New York.

Dr. William C. Cooley as assistant programme engineer on the Rover project, the research activity directed toward a nuclear rocket engine which is now being conducted under a U.S. Air Force contract by the Rocketdyne division of North American Aviation.

Tours

Mr. A. S. Humphrys, manager of the Australian office of Humphreys and Glasgow, is on a month's visit to the company's London headquarters. During his stay he will study the latest trends in several of the concern's products, including nuclear power-plants.

Mr. H. A. Ball, a senior sales engineer of the Solartron Electronic Group, has recently returned from a four-week tour of the Middle East.

Mr. R. E. Burnett, general manager, and **Mr. S. G. Spooner,** production manager of Marconi Instruments, are on a three-week marketing tour of the U.S.A.

Obituary

Nuclear Engineering records, with regret, the death of the following personalities:

Mr. G. S. Towler, chief technical officer, operations branch, Industrial Group, U.K.A.E.A.

Mr. G. A. S. Harvey, president of G. A. Harvey and Co. (London), Ltd., on May 28, at the age of 74.

Mr. G. C. Cunningham, O.B.E., joint managing director, Racal Engineering, on May 16.

Mr. T. W. Aiken, sales director, Bryan Donkin Co., on May 20, at the age of 55.

The Queen's Birthday Honours

KNIGHTS BACHELOR

Friston Charles How, secretary, Atomic Energy office; **Willis Jackson,** director of research and education, Metropolitan-Vickers Electrical Co.; **John Sidney Pickles,** chairman, South of Scotland Electricity Board.

G.B.E.

Rt. Hon. Baron Walter McLennan Citrine, lately chairman Central Electricity Authority.

K.B.E.

Reginald John Ayres, deputy secretary, Ministry of Power.

C.B.E.

D. Bellamy, chairman, Yorkshire Electricity Board; **E. K. Cole,** chairman and managing director, E. K. Cole; **J. Corner,** senior superintendent, physics division, A.W.R.E., Aldermaston; **G. H. Wilson,** chairman and managing director, Laurence Scott and Electromotors.

O.B.E.

W. G. Marley, chief radiological safety officer, A.E.R.E., Harwell; **R. P. M. Wright,** engineering manager, Harland and Wolff.

M.B.E.

H. A. Brooke, engineer 1, A.W.R.E., Aldermaston.

B.E.M.

A. W. P. Davy, laboratory worker, A.W.R.E., Aldermaston; **E. F. Foreman,** foreman, research laboratories, G.E.C.; **R. W. Ruding,** technician 3, A.E.R.E., Harwell.

Industrial Notes

Reactors of the World. The first series of pull-out drawings of reactors published in *Nuclear Engineering* has just been reissued in booklet form by Temple Press. The price is 10s. 6d. net from all booksellers or 11s. 2d. by post from Temple Press Limited, Bowling Green Lane, London, E.C.1.

Evershed and Vignoles opened their new office block at the company's Chiswick works on June 11. Sir Christopher Hinton, K.B.E., F.R.S., chairman, Central Electricity Generating Board, who performed the opening ceremony, spoke warmly of the part that Evershed and Vignoles had played in the development of instrumentation. More recently, Evershed and Vignoles have secured several contracts for physical instruments and recorders for nuclear power stations. The Chiswick works has a floor area of almost 200,000 sq. ft and employs over 1,700 people.

Dynatron Radio have just opened a new factory at St. Peter's Road, Furze Platt, Maidenhead. For the first time in several years, the development group, sales and service departments, head office and factory personnel are now at the same address. The new buildings cover an area of 40,000 sq. ft. They will enable the company to expand its production facilities for nucleonic instrumentation and radio and TV receivers.

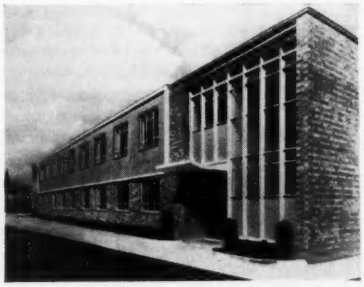
Honeywell-Brown changed its name to **Honeywell Controls** on June 1. On the same date all head office departments and the London branch office moved from Perivale to a new building in Greenford. The address now is Ruislip Road East, Greenford, Middlesex. Telephone: Waxlow 2333.

Welding Supplies, who have provided large quantities of O.K. Unitrodes for welding at Calder Hall, Berkeley and Bradwell, celebrated their 25th anniversary on May 16.

CIBA (A.R.L.) is the new title of Aero Research of Duxford, Cambridge, the manufacturers of synthetic resin adhesives.

Metering Pumps is the name of a new company formed by the chemical pump division of the Candy Filter Co. The company is located at 21 The Mall, Ealing, London, W.5. Telephone: Ealing 4024.

Abbey Panel and Sheet Metal Co. have moved to Bayton Road, Exhall, Coventry. Telephone: Bedworth 2071. The premises at Old Church Road, Little Heath, Coventry are now occupied by an associate company, Abbey Engineering Co. (Coventry).

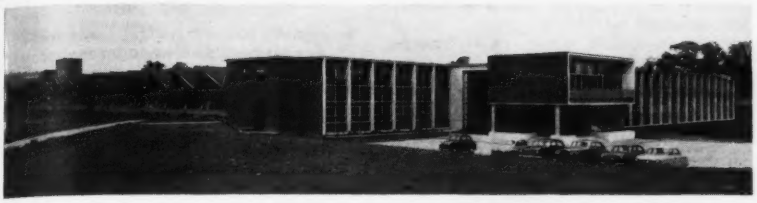


New factory and offices for Dynatron Radio at Maidenhead.

B.I.M.C.A.M.—the British Industrial Measuring and Control Apparatus Manufacturers' Association—has moved to new offices at 9 Argyll Street, London, W.1. Telephone: Regent 0568.

Firth Cleveland Instruments, a subsidiary of Simmonds Aerocessories, on June 6 opened a new fuel-flow test house at the Treforest trading estate, near Cardiff. Facilities are provided for calibrating and production testing flowmeters, water separators, valves and other fluid handling equipment. The new test house was opened by the Minister of Supply, the Rt. Hon. Aubrey Jones, M.P. Firth Cleveland products include remotely operated valves and flow indicators; the company recently supplied a large quantity of control-rod position indicators for DMTR, Dounreay.

Nuclear Civil Constructors, the firm recently formed by Trollope and Colls, and Holland and Hannen and Cubitts, has taken over offices at 52-55 Carnaby Street, London, W.1. Telephone: Regent 2141-5.



Foxboro-Yoxall recently opened this new instrument factory at Redhill.

Foxboro-Yoxall's new factory at Redhill will enable the company to expand still further production of flow controllers, recorders and other instruments. At the opening ceremony on May 22 the company welcomed a large number of guests including Mr. Carl Sullivan, vice-president of the Foxboro Co., of U.S.A. The new office block provides 24,000 sq. ft and includes a training school for customers' personnel. The single-storey factory is 85,000 sq. ft and embodies many new features. For example all services are distributed from a tunnel running the length of the factory. Ancillary buildings include a power house and a 12,000-sq.-ft restaurant.

Texas Instruments Inc., of Dallas, Texas, are opening, on June 23, a new 310,444-sq.-ft factory for the production of transistors and other semiconductor devices. The company plan to use the signal from the American satellite Vanguard to cut the traditional ribbon.

Texas Instruments announce a number of substantial price reductions in their range of silicon transistors and rectifiers. Small signal transistors are reduced by 20% to 30%; medium and high power units from 5% to 12% and rectifiers by 10%.

Vacu-B'ast, designers and manufacturers of the Vacu-Blast closed-circuit system of shot blasting have moved into larger premises at Bath Road, Slough.

Imperial Chemical Industries' new plant at Waunarlwydd, near Swansea, is believed to be the first in the world devoted solely to the production of wrought titanium.

Vacuum Metallizing Processes has been formed by Continental Can Co., of New York, and Vacuum Research (Cambridge) to promote a jointly patented process for metallizing plastic films and paper.

American Machine and Foundry, of New York, has been awarded a contract for a 5 MW pool-type research reactor by the Austrian Study Group for Atomic Energy. The reactor will be the main instrument of a nuclear research centre near Vienna: scheduled completion date is December, 1959.

Metropolitan-Vickers Electrical exhibited various equipments of nuclear interest at the recent international trade fair at Vancouver. Models of an A.E.I.-John Thompson reactor for Berkeley, and a Newton Victor Orbitron cobalt therapy unit were displayed, together with photographs showing Met-Vick's work on ZETA.

Met-Vick recently received an order from the South of Scotland Electricity Board for the 132-kV air-blast switchgear for Hunterston. The order is worth about £400,000 and is unusual because nearly all the equipment will be indoor-mounted.

The Vokes Group held a special display of products in Manchester during May. The parent company featured their new Maxivee filter element together with the Autoroll, an automatic screen filter for air conditioning and ventilation. Vokes Genspring exhibited the new M range of constant support hangers for overcoming thermal expansion problems in pipe lines. Another subsidiary, Stream-Line Filters, displayed pressure-operated filters for lubricating oils.

Ransome and Marles Bearing Co. have moved their South-West area office to larger premises at Transom House, Bristol. Telephone: Bristol 20437-8.

Metal Atomizing and Processing Corporation, a subsidiary of Jacobus Mining, has been formed to exploit powder metallurgy techniques.

Rocky Mountain-Pacific Nuclear Research Group will pool the resources of eight leading U.S. utility companies and General Atomic division of General Dynamics Corporation to further research into high temperature nuclear fission, including a study of direct generation of electricity from the heat produced in a reactor. Over $500,000 will be provided by the group during the next two years.

D.S.I.R.'s Mechanical Engineering Research Board at East Kilbride, Glasgow, is to intensify research on problems affecting nuclear engineering. The recently published annual report specifically mentions the manufacture of beryllium fuel element sheaths, the development of high-speed pumps, rotary heat exchangers and the effects of irradiation on various materials.

BX Plastics are to manufacture and market a range of irradiated polythene tapes, developed by Tube Investments research laboratories. Special sizes and thicknesses of tape will be produced and, by arrangement, will be processed on T.I.'s high energy accelerator. High energy radiation increases the resistance of polythene to high temperature and stress cracking.

Padley and Venables, who specialize in the supply of stainless steel, have moved to a new factory at Middlemore Lane West, Aldridge, nr. Walsall, Staffs.

Crossley Bros., of Manchester, have supplied eight 500 kW Diesel-engined automatic standby generator sets to Chapel Cross nuclear power station. There are four separate engine-rooms, one per reactor, each housing two sets. The engines are 800-b.h.p. Crossley HSN six-cylinder two-cycle scavenge pump Diesels each direct coupled to a Brush 240 V d.c. generator.

The Distillers Co. announce that their chemical division has supplied liquid carbon dioxide bulk storage and evaporation equipment for Chapel Cross. The first of five storage tanks was delivered on May 20.

George Kent have opened a branch office in the heart of the Ruhr at 54 Westparkstrasse, Krefeld.

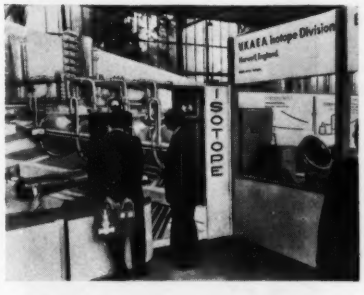
Jeltek is the name of a new company formed by J. E. Lesser and Sons, of Hounslow, to undertake the manufacture and marketing of Jeltek protective clothing.

TREAT—Transient Reactor Test Facility, a unique reactor for investigating the effect of extreme nuclear conditions on fast reactor fuel elements—will be completed this year at the A.E.C.'s National Reactor Testing Station near Idaho Falls. Designed by Argonne National Laboratory, TREAT will cost $1 million. The reactor will provide a high intensity short duration pulse of nuclear energy, thus causing intense heat in the sample under test.

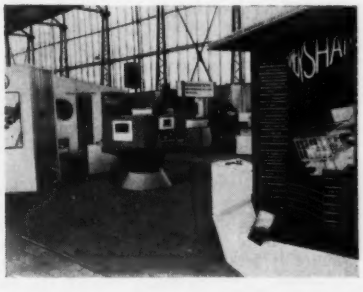
Atomics International announce that their new 10-watt model 77 laboratory reactor is now in operation at Canoga Park. Fuelled with 20% enriched uranyl sulphate, the model 77 is only 8 ft high and 8 ft diameter. There are nine experimental facilities.

G. and J. Weir, of Glasgow, have received an order from English Electric for 10 electrofeeders for Hinkley Point. The order includes eight main feed pumps each discharging 1,150,000 lb/h at 882 p.s.i., and two emergency pumps each with an output of 120,000 lb/h at 882 p.s.i.

Kelvin Hughes has just initiated a new sales drive in Europe. Ferried by a converted tank landing craft, two specially equipped mobile demonstration units—one looking after the marine side of the business, the other industrial instruments, will tour Eastern Europe and the Common Market countries.



U.K.A.E.A. were prominent amongst the British exhibitors at Achema, the international exhibition dealing with chemical apparatus held in Frankfurt during June. The stand, covering an area of 1,400 sq. ft, was essentially devoted to applications of radioactive isotopes. The location of leaks in underground pipelines, the use of light sources which require no fuel or maintenance, control of insect pests, elimination of static electricity, thickness measurements and industrial radiography were all featured on the stand. Visitors to the exhibition showed great interest in the Amersham isotope export service.



Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

Liquid-level Transmitter

Foxboro-Yoxall have added to their range of pneumatic transmitters a direct-mounted liquid-level transmitter using the 13A force balance design to measure liquid level in open or closed vessels. The unit, model 13FA, transmits an output air signal to standard 3-15 p.s.i. receiver recorders and controllers which may be locally or remotely mounted. The sensing diaphragm is flange mounted to the side of the tank. This means that there are no process piping problems and the 13FA is thus particularly suited for the measurement of difficult fluids of the viscous and slurry types.

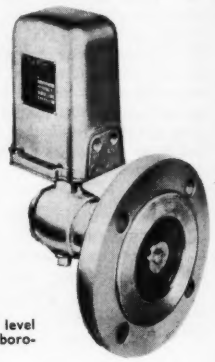
The 13FA operates equally well on open or closed vessel applications. In open vessel measurement only the high-pressure side of the pressure-measuring diaphragm and the raised serrated face of the cell flange are in contact with the process fluid. The low-pressure side of the diaphragm is vented to atmosphere. For closed-vessel measurement only an equalizing leg is required. If a wet leg is used an adjustable-range suppressor attachment gives forward reading measurement and corrects for cold leg conditions.

The instrument may be used under the most arduous corrosion conditions and to this end is supplied in three forms: (a) with cadmium-plated mild-steel body and flange diaphragm in stainless steel; (b) all in stainless steel, and (c) body flange and diaphragm in stainless steel with flange and diaphragm plastic coated.

The twin diaphragm measuring element, liquid filled and with a solid stainless-steel core, is completely protected against accidental overrun. It covers the full range of the instrument—0-20 to 0-850 in. of water. Range changing is a simple matter of moving a range wheel up or down a range rod fitted with a calibrated range scale. The instrument is suitable for use on pressures up to the rating A.S.A. 300 at 350° F maximum vessel temperature. For radioactive locations there is a modified version of the 13FA.

(Foxboro-Yoxall, Ltd., Redhill, Surrey.)

1125



Model 13FA liquid level transmitter by Foxboro-Yoxall.

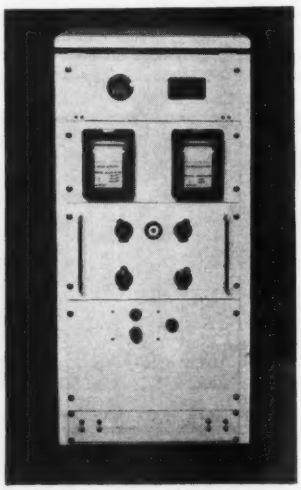
Detecting Radioactive Dust

A radioactive dust monitor which can be arranged for alpha or beta particle detection or, alternatively, alpha and beta detection, was recently demonstrated by the manufacturers, Rotheroe and Mitchell.

Monitoring alpha particle radiation from airborne dust the unit is capable of detecting 10 maximum permissible levels of plutonium-239 in less than one hour and will detect greater activities in a shorter period. A constant displacement pump draws the air being monitored through a continuously moving strip of filter paper; dust is deposited on the paper and transported with it past two scintillation detectors. The detectors are spaced apart so that 30 minutes elapse while the paper moves from the first to the second. Pulses from the first detector are fed into a ratemeter circuit, the output voltage of which is linearly proportional to the pulse rate.

A second ratemeter, connected to the first detector for two minutes in every 30, provides for the remaining 28 minutes a constant output voltage proportional to the activity of the dust monitored during the two-minute period. The output voltage of this ratemeter continuously depresses the zero of a third ratemeter connected to the second detector. If the dust collected is associated only with naturally occurring short-lived alpha emitters such as polonium-214, the ratio of the activity at the first and second detectors will be approximately constant, the second and third ratemeters are adjusted so that in these circumstances the output of the third ratemeter will be zero. If a long-lived alpha emitter is present a positive output will be produced. Two recorders indicate the outputs of the first and third ratemeters and a Klaxon siren can be made to operate if either output exceeds a pre-set level.

For monitoring beta radiation from dust in laboratory air, the dust deposited on the paper is transported past a beta sensitive geiger tube. Pulses from the tube are fed into a ratemeter circuit, the output voltage of which is linearly proportional to the pulse rate. A recorder is used to provide an indication of the beta activity. There are also facilities for ensuring that a Klaxon siren shall operate if the activity exceeds a pre-set level. A second G.M. tube, sensitive only to gamma radiation, detects gamma background activity. A recorder and alarm circuit are also associated with this detector. The first G.M. tube is sensitive to gamma radiation in addition to beta radiation. As it is desirable that the output of the first ratemeter shall be proportional to beta activity only, arrangements are made to automatically compensate for the gamma background by using pulses derived from the second detector.



Radioactive dust monitor (Rotheroe and Mitchell).

Finally, for monitoring the radioactivity of dust passing through ventilation ducting, an equipment arranged to detect both alpha and beta radiation can be supplied. A constant displacement pump draws air, via a flexible pipe from the ducting, through a continuously moving strip of filter paper. Dust is deposited on the paper and transported with it, first past a scintillation screen detecting alpha radiation and then past a beta sensitive G.M. tube. A photomultiplier associated with the scintillation screen produces pulses at a rate proportional to the alpha activity; these are fed into a ratemeter circuit, the output voltage of which is linearly proportional to the pulse rate. A recorder continuously indicates the alpha activity and a Klaxon siren is operated if a pre-set activity level is exceeded.

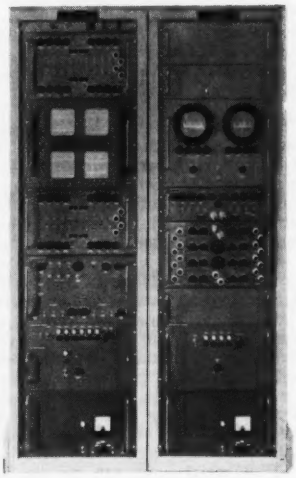
The G.M. tube is connected to a similar ratemeter, recorder and alarm circuit so that the beta activity is also continuously monitored. The G.M. tube is sensitive to gamma radiation in addition to beta radiation. As it is desirable that the output of the ratemeter shall be proportional to beta activity only, a second G.M. tube, sensitive only to gamma radiation, is used automatically to compensate for the gamma background in the vicinity of the equipment. Provision is made for connecting external indicators duplicating the readings on the recorders and a remotely situated Klaxon operating in parallel with the internal siren if required. In addition, facilities are incorporated for switching external apparatus at the same time as the sirens are operated.

(Rotheroe and Mitchell, Ltd., Electronics Division, 82 Cox Green Road, Maidenhead, Berks.)

1126

Multi-channel Oscilloscope

Where many rapidly changing phenomena have to be measured accurately simultaneously, a multi-channel oscilloscope is often the only answer. Recently Cawkell Research and Electronics demonstrated an extremely interesting multi-channel recording and memory storage unit—basically similar to a model previously supplied to Harwell for measuring purposes on the ZETA project.



Cawkell multi-channel oscilloscope.

The instrument, believed to be the most comprehensive of its type manufactured in the U.K., comprises an eight-channel oscilloscope with provision for photography, together with a two-channel storage oscilloscope. Both assemblies, complete with all the associated equipment, are housed in a two-bay 6-ft rack.

An important feature of the equipment is that the storage tubes retain the waveform of a non-recurrent transient indefinitely for detailed visual examination, whilst the waveforms on the four-gun c.v.t. can be photographed for subsequent measurement.

At the same demonstration other Cawkell equipment included a range of non-destructive testers, stabilized power supplies and pulse/time measuring equipment.

(Cawkell Research and Electronics, Ltd., 6-8 Victory Parade, Southall, Middlesex.)

1127

High-temperature Insulation

Although primarily developed for the aircraft industry, Thermoflex insulation blankets have many applications in nuclear engineering—particularly where a replaceable blanket is specified. Thermoflex blankets comprise sections pre-formed by sandwiching refractory fibre felt between two outer skins of .004-in. stainless steel. These skins are either dimpled (P-type) or crimped (K-type), which not only strengthens the skin but increases resistance to abrasion or accidental damage. The circumferential edges are of channel construction and the respective half sections are normally laced together around a pipe by means of stainless-steel wire. A specially designed joint provides adequate insulation at the overlapping edge. Edge-sealed access holes can be incorporated where required.

The complete blanket is remarkably strong in relation to its average weight of .65 lb/sq ft. Because the blanket retains its shape and strength, even after exposure to temperatures up to 1,100°C, it can be removed and replaced intact should maintenance to the pipework or insulated structure become necessary.

(Delaney Gallay, Ltd., Vulcan Works, Edgware Road, Cricklewood, London, N.W.2.)

1128

G.P. counting equipment by Airmec.

Versatile Counting Equipment

Airmec's 1339A general-purpose counting equipment has been designed and developed in conjunction with A.E.R.E., Harwell, to provide comprehensive scaling facilities for geiger and scintillation counters used in the assay of alpha, beta and gamma samples. The 1339A equipment comprises two basic units—power supply and scaler—supplemented by suitable accessory sub-units for beta/gamma counting to serve any of the alcohol quenched types of counter and most halogen quenched counters or for alpha counting with scintillation type probes. Essential features of the scaler include facilities for slow-speed scaling and with a choice of paralysis times, together with automatic control.

The accessories include a quenching sub-unit for use with geiger counters for beta/gamma counting and an amplifier/discriminator sub unit for alpha counting with scintillation type probes. A fast scaler sub-unit can be supplied for operation where the sample disintegration rate is high.

(Airmec, Ltd., High Wycombe, Bucks.)

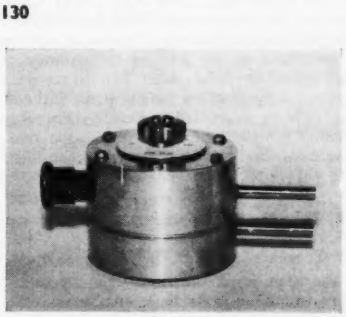
1129

Differential Switch

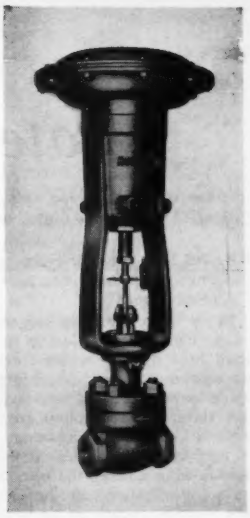
A differential pressure switch for operation in corrosive and non-corrosive liquids or gases has just been introduced by Appleby and Ireland. The internal arrangement comprises a stainless steel diaphragm interposed between two body sections and sealed by two silicon rubber gaskets. The stainless steel enclosure has two 6-in. by .346-in. O.D. by ¼-in. s.s. tube connections for attaching flexible tubing or for welding in a pipe line. An adjustable contact enables the switch to be pre-set. Standard range is 0 to 20 in. H_2O, with static pressures of up to 150 p.s.i.

(Appleby and Ireland, Ltd., Kempshott Park, Kempshott, Basingstoke.)

1130



Differential pressure switch Appleby and Ireland).



Diaphragm control valve.

Diaphragm Valves for Process Control

Honeywell Controls are now making a comprehensive range of diaphragm control valves, complementing their established range of miniature and conventional pneumatic controllers.

Single-seated valves give throttling action with tight shut-off. A choice of plug types provides equal percentage, linear or quick-opening action. Sizes range from 1 in. to 8 in. Double-seated valves, for pressure-balanced throttling action on processes where fluid pressure is high, offer the same range of plug types, with the addition that equal percentage plugs can be either V-ported or contoured. Sizes are from 1 in. to 8 in.

Low-flow valves are available in body sizes from ½ in. to 1 in. Reduced port sizes ranging from ⅛ in. to ½ in. give flow coefficients suitable for low-flow control, both in the laboratory and on the process. Plug action is equal percentage. Three-way valves, single- and double-seated, can be piped for mixing or diverting service. Design ensures that flow always tends to open the plug, gives increased stability and eliminates slamming. Body sizes range from ½ in. to 8 in.

(Honeywell Controls, Ltd., 1 Wadsworth Road, Perivale, Middlesex.)

1131

Raised Floor for DIDO

A raised floor which can be easily removed has been erected over the DIDO reactor at A.E.R.E., Harwell. Sections of the floor can be lifted to provide access to a steel box casing on the top of the reactor, thus facilitating future experimental work. The floor, constructed by F. A. Norris and Co. to Head Wrightson design consists of heavy baffle plates cut to profile and welded on site. The floor will take a 25-ton load on any section. Its maximum dimensions are 20 ft by 20 ft and the weight is 9½ tons.

Another sub-contract handled by Norris for Head Wrightson involved welding up the biological shield for the PLUTO reactor ordered by the Danish Government and scheduled for installation at Risoe.

The specification called for a 1-in. thick M.S. outer and base shield supported by heavy built-up electrically welded fabricated columns. The shield has a ½-in. top plate with special steel supports.

(F. A. Norris and Co., Ltd., Crown Works, Garth Road, Morden, Surrey.)

1132

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 788,284. Nuclear reactors. To: Stichting Reactor Centrum Nederland (Netherlands).

In a gas-cooled heterogeneous reactor using, e.g., carbon dioxide under pressure, good heat transfer without excessively high temperatures is only possible by giving the fissile material a good heat-conducting structure (layers of aluminium around the fissile material). There is, however, another way of cooling a nuclear reactor by means of a fluid flowing through the reaction zone where such considerations do not apply. In the new reactor, which is preferably a homogeneous reactor, one or more bodies of porous material are provided in the reaction zone consisting of or containing an intimate mixture of fissile material and heat-distributing material, which may be, or include, moderating material. The fissile material is not present as a metallic body but is distributed throughout the porous (sponge or coral-like) material formed, e.g., by a sintering process. The heat-distributing material may have only a small neutron-capture section, but should have a reasonably good heat conductivity and high heat resistance. The heat is thus distributed over a large area and can be effectively taken up by the cooling fluid. Beryllium oxide, beryllium carbide or carbon, which have moderating properties, may be used. Other heat distributors (without moderating properties) are compounds of bismuth, magnesium, lead, phosphorus, silicon, zirconium and/or aluminium (bismuth trioxide, magnesium oxide, silica, magnesium, silicate, zirconium silicate, magnesium pyrophosphate). The heat distributing material and any separate moderating material may contain breeder material (U^{238} and/or thorium, particularly their oxides or carbides). The fissile material may be U^{235}, U^{233} and/or Pu, or their compounds (oxides; carbides). No fissile particles should be greater than 50 microns. The gaseous fluid is preferably pumped through the reaction zone under pressure. Dependent on the heat distributing material, oxygen, carbon monoxide, helium, hydrogen, deuterium or a dispersion of liquid in a gas may be used as cooling fluid. In such a reactor much higher temperatures are admissible in the reaction zone (600° to 1,500°C as against 300°C in known reactors of this kind).

B.P. 788,288. Nuclear reactors. To: Sulzer Frères Soc. An. (Switzerland).

The reactor comprises a heterogeneous part and a homogeneous part, and criticality can only take place when they are combined to form a complete reactor. Such a reactor may comprise a main vessel containing a moderator liquid (water enriched with heavy water) in which a grid of rods of natural uranium only slightly enriched with U^{235} is disposed constituting the heterogeneous reactor. The homogeneous part consists of vessels inside the main vessel filled through pipes with homogeneous fuel liquid (fissile material and the same moderator liquid as the main vessel). Variations in the concentration of fissile material in the fuel liquid serve for coarse regulation of the reactor as a whole. The heat generated is removed from the reaction vessel through the moderator liquid pumped to a heat exchanger and then returned to the vessel.

B.P. 788,295. Electrodeposition of titanium, zirconium, hafnium, tantalum, vanadium, niobium, chromium, molybdenum and tungsten. To: Horizons Titanium Corp. (U.S.A.).

It has been found that when cladding base metals with corrosion resistant metals by electrolysis in a fused salt bath alloying takes place between the deposited metal and the base cathode metal on using a combination of a specific range of higher bath temperatures and a specific range of cathode current densities.

B.P. 788,383. Beryllium hydroxide. To: Pechiney Compagnie de Produits Chimiques et Electrométallurgiques (France).

It is often advisable to use beryllium hydroxide as an intermediate product when preparing beryllium oxide, or a salt of beryllium. It has now been found that there is a possibility of directly precipitating beryllium hydroxide, in the β form, from a solution of a beryllium salt by neutralizing the solution with an alkali base (ammonia) under controlled conditions of pH (between 6 and 8.5) and of temperature (80°C and boiling). Hydroxide ready precipitated may act as seed.

B.P. 788,721. Treatment of metals prior to electro-plating. R. A. U. Huddle, O. Flint. To: U.K. Atomic Energy Authority.

Shot-blasted surfaces are given a coating of copper by displacement from a copper salt solution. The metals so treated may be uranium, zirconium, titanium, tantalum, niobium, molybdenum, tungsten or vanadium. The protective metal is nickel.

B.P. 788,804. Formation of hard intermetallic coatings from electro-deposited layers of titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum and tungsten. To: Horizons Inc. (U.S.A.).

A cladding layer of the refractory metal is formed on the base metal (steel, which must contain at least one of the elements carbon, nitrogen, boron and silicon). Either simultaneously or subsequently a transfer of a refractory metal-hardening element from the mass of the base metal to the cladding layer of the refractory metal is effected. A fused salt bath is used, composed essentially of a halide of the refractory element and a diluent halide salt. The base metal incorporating the intermetallic compound-forming element (carbon, nitrogen, boron or silicon) is immersed in the bath as the cathode of an electrolytic cell. After deposition of a layer of the refractory metal on the cathode, the cathode is heated sufficiently to effect thermal diffusion of the intermetallic compound-forming element from the base metal into the refractory layer.

B.P. 788,838. Electroplating protective metal coatings on uranium metal. To: Atomic Energy of Canada, Ltd. (Canada).

The uranium is subjected to anodic treatment in an aqueous bath containing carboxylic radicals to ensure a surface free from oxide and pitting.

B.P. 788,902. Gas-cooled nuclear reactors. E. Long, W. Rodwell. To: U.K. Atomic Energy Authority.

Refers to sealing means between the graphite structure and the pressure vessel to compensate for relative movements in radial and axial directions as temperatures change. The sealing means must allow internal assembly with the minimum of internal working. A solution has been found by providing the wall of the pressure vessel with an interior flange supporting a sectionalized ring of close-fitting flexible webs, which are directed radially inwards into slots in the graphite structure and are thickened at their inner edges to fit closely into the slots. Preferably, two spaced rings of webs are provided for safety purposes.

B.P. 788,926. Production of heat and corrosion resistant bodies. A. Blainey. To: U.K. Atomic Energy Authority.

The use of aluminium as a covering for uranium rods does not permit higher temperatures of operation of thermal fission reactors. Relatively high temperatures, however, can be reached when using beryllium or zirconium, i.e., materials of high melting point, for enclosing uranium and/or thorium. The constituent materials are formed into elements or units to the cross-sections required by powder metallurgy which permits the use of substances of small neutron-capture cross-section in a non-ductile state. Thick sheaths are thus tolerable, good contact can be secured in a simple manner, accurate machining of uranium metal and drawing of metal tubes can be dispensed with, and the closure of the sheath can be effected during manufacture.

B.P. 789,022. Nuclear reactor. W. M. Brown. K. J. Mitchell. To: General Electric Co., Ltd.

Refers to reactors with a (gaseous) cooling medium operating under considerable pressure. This means that when changing fuel elements or, e.g., control rods, the reactor vessel must first be brought down to atmospheric pressure. This procedure is not necessary when using an auxiliary vessel to be connected with the enclosing vessel of the reactor the pressure in the auxiliary vessel being matched to that in the reactor vessel and then supplying, e.g., fuel elements from the auxiliary vessel and also receiving elements to be changed in this vessel.

B.P. 789,117. Nuclear reactors. To: Stichting Reactor Centrum Nederland (Netherlands).

Refers to reactors operating with water or heavy water containing fissile material in solution and/or in a finely divided state. The walls of the reaction zone, any solid structure within this zone, and the reflector surrounding it are constructed entirely of graphite using neither zirconium (expensive when pure) nor aluminium (not corrosion resistant at high temperatures).

B.P. 789,213. Device for detecting radioactivity. To: U.K. Atomic Energy Authority (U.S.A.).

Portions of a screen with a fluorescent surface arranged on a casing impervious to ordinary light but permeable to rays emitted by a radioactive surface can be covered with radioactivity-absorbent elements (lead strips) so that fluorescent and non-fluorescent portions provide contrasting patterns on the screen and aid the (military) observer in the detection of fluorescence. The variations in the patterns observed also permit to find the location of the radioactive source.